The Effect of Challenging Inhibitory Tasks on Subsequent Susceptibility to Unconscious Influences

Angela Gurney

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School of Psychology

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Statement of Declaration

The work in this Thesis is presented in an ‘article format’ in which the middle chapters consist of discrete articles written in a style appropriate for publication in peer-reviewed journals in the field. The first and final chapters present synthetic overviews and discussion of the field and the research undertaken.

I hereby declare that this thesis has not and will not be, submitted in whole or in part to another university for the award of any other degree.

Signed:

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University of Sussex

Angela Gurney

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Summary

Previous research has examined a variety of behavioural effects, thought to stem from mental exhaustion, following the prior use of inhibitory control. Here we attempt to examine whether such effects are apparent in unconscious behaviours. Chapter 1 demonstrates no effect of prior use of inhibitory control on subsequent susceptibility to subliminal priming of neutral (Experiment 1) and reward (Experiment 2) terms. Chapter 2 explores whether the prior use of inhibitory control influences the degree of susceptibility to an alternative source of influence, hypnotic induction, and provides the novel finding that inhibitory impairment does not affect hypnotic response. Chapter 3 utilises behavioural and fMRI imaging data to examine changes in a conscious facet of human experience often moderated by unconscious influences: emotion regulation. The results support a period of increased mood lability following a challenging inhibitory control task. However, we were unable to provide evidence of any underlying change in cortical activation and connectivity. Finally, Chapter 4 investigates whether this heightened mood lability following prior inhibitory control would also be mirrored in ratings of emotion attributed to positive and negatively valenced images (Experiment 1) and additionally, whether a mindfulness induction, previously documented to improve emotion regulation, would reduce individuals' perception of the degree of valence attributed to the same images (Experiment 2). Contrary to predictions, we report substantial evidence for no effect of prior inhibitory control or a brief mindfulness manipulation on subsequent ratings of emotionally valenced stimuli.

Taken together the research indicates that mental exhaustion arising from the use of self-control appears to have no effect on susceptibility to unconscious priming, hypnotic suggestions, and no effect on the perception of emotionally valenced images. However, prior use of inhibitory control does appear to affect the degree of emotional lability experienced following music.

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Introduction

Literature Overview

Self-control is a defining feature of the human race and refers to the ability to regulate urges and resist temptation in the pursuit of competing goals. It is one aspect of executive inhibitory control and is often referred to colloquially as willpower. Effective self-control presents many opportunities for personal growth and goal attainment. As such, its practical importance is of great significance with the failure to exert self-control held to contribute to many of society's challenges such as obesity, debt, drug and alcohol abuse, criminality, and racial discrimination (Inzlicht & Schmeichel, 2012). In fact, studies have shown that self-control is a more powerful predictor of academic success than IQ itself (Duckworth & Seligman, 2005). Even when controlling for socioeconomic status and intelligence, those with higher levels of self-control as children, grow into adults with better physical and mental health with fewer criminal convictions, less incidence of substance abuse and better financial security (Moffitt et al., 2011).

Self-control has been a hot topic of research for several decades and has predominantly been experimentally explored using a dual task paradigm, which requires participants to complete two consecutive tasks requiring some form of inhibitory control, in order to examine the extent to which exerting control on one task affects the degree of control which individuals apply to subsequent tasks. For the first task, participants are typically split into two conditions requiring them to complete either an easy or difficult version of a task requiring inhibitory control. Participants in both conditions subsequently complete a further inhibitory control task on which their performance is compared. The literature consists of over 300 studies which report a limited capacity for further attempts at self-control following the difficult inhibitory task (contrast Dang, 2017; Hagger, Wood, Stiff, & Chatzisarantis, 2010, with Carter & McCullough, 2014), demonstrated via worse performance on the second task in comparison to their control counterparts who completed the easy task. The research shows that the reduced capacity for self-control on the second task results in heightened aggression (DeWall, Baumeister, Stillman, & Gailliot, 2007), risk-taking (Fischer, Kastenmüller, & Asal, 2012), impulsivity (Vohs & Faber, 2007), over-eating (Hofmann, Rauch, & Gawronski, 2007; Vohs & Heatherton, 2000), underachievement (Schmeichel, Vohs, & Baumeister, 2003) and greater levels of stereotypical responses on tests of implicit racial bias (Govorun & Payne, 2006).

Despite the importance of self-control in shaping human experience, attempts to model self-control (explored further below) have thus far proven inconclusive and consequently our current understanding of the mechanisms involved is fundamentally limited. More research is necessary to determine how our cognition and behaviour is affected by the prior use of inhibitory control. Whilst much research has demonstrated the effect of prior self-control on subsequent conscious behaviours, it is interesting to consider how it might similarly affect how we respond to unconscious influences. Over the course of this thesis I therefore aim to investigate how mental exhaustion, arising from the prior use of inhibitory control, affects how we process, respond, or attend to unconscious influences.

Models of Self-Control

The Resource (or Strength) model of self-control has dominated for some time and portrays self-control as a capacity which relies upon an internal and limited resource which once used, takes time to replenish (see Baumeister, Bratslavsky, Muraven, & Tice, 1998). The model proposes that exerting willpower consumes this resource, resulting in ‘ego-depletion’; a state in which further attempts to exert self-control are increasingly difficult (Hagger, Wood, Stiff, & Chatzisarantis, 2010). Whilst the self-control literature outlined above appears to support this account to a degree, the extent to which the findings can be seen as evidence for the Resource model has been widely disputed (see Inzlicht & Schmeichel, 2012) and attempts to characterize the nature of the 'resource' suffering depletion have thus far been without success. Early proposals that the resource may be blood glucose levels (Gailliot, Plant, Butz, & Baumeister, 2007; Masicampo & Baumeister, 2008) have since been robustly challenged (Beedie & Lane, 2012; Dang, 2017; Job, Dweck, & Walton, 2010; Kurzban, 2010; Martijn, Tenbult, Merckelbach, Dreezens, & de Vries, 2002; Schmeichel & Vohs, 2009; Tice, Baumeister, Shmueli, & Muraven, 2007) and without a means to pinpoint the resource in question, the model is fundamentally limited.

An alternate explanation comes from the Process model of self-control, a model which proposes a shift in motivational orientation and attentional focus following acts of self-control at time 1 (Inzlicht & Schmeichel, 2012). That is, after the initial act of self-control, individuals become less motivated to exert control and more motivated to indulge as attention is shifted away from cognitive and affective cues signalling the need for self-control, and toward cues signalling rewards. One proposed account for this shift in motivation is 'self-licensing'; the idea that after exerting self-control once, individuals feel that they can then justify indulgences (Inzlicht & Schmeichel, 2012). Support for the process model comes from studies demonstrating that offering rewards for self-control at time 2 or boosting motivation to exhibit control appears to counteract Baumeister et al.'s (1998) ego-depletion effect (Muraven & Slessareva, 2003).

Other more recent models of self-control continue this trend toward a mechanistic revision of self-control. For example, the Opportunity Cost Model (Kurzban, Duckworth, Kable, & Myers, 2013) depicts self-control as reliant on computational mechanisms which weigh up the costs and benefits of a given task in order to assess to which task executive functions are most usefully deployed. It is believed that mental fatigue, experienced as effort, is an adaptive and necessary signal to cue goal switching and the reallocation of processes to a more beneficial task (Kurzban et al., 2013).

A neurological account of self-control comes from Heatherton and Wagner's (2011) balance model which depicts self-control as a precise balancing act between brain regions such as the lateral and medial areas of the prefrontal cortex (PFC) responsible for inhibiting impulses, and those regions responsible for monitoring the reward and salience of stimuli such as the orbitofrontal cortex (OFC) and Striatum. Self-control fails when the impulse is stronger than the processes needed to inhibit it or when frontal executive processes are disrupted, such as in the case of the ‘ego-depletion’ effect.

Opprobrium and Reappraisal of the Depletion Literature

The self-control literature, and the Resource model in particular, has recently become the subject of much debate. Carter and McCullough (2014) reported an incidence of high rates of publication bias in Hagger et al.'s (2010) meta-analysis which had led to an overinflated medium to large effect size (d = 0.62, 95% CI = 0.57, 0.67). In response Carter, Kofler, Forster, and McCullough (2015) published their own meta-analysis including a number of unpublished papers and found little evidence of the ego depletion effect (adjusted g = 0.24, 95% CI = 0.13, 0.34). Furthermore, a registered replication report, involving 23 laboratories (N = 2141) similarly found little to no evidence of ego-depletion (Hagger et al., 2016). Taken together, these studies sparked high levels of interest regarding the reliability and replicability of the self-control literature.

A key issue within the literature is ensuring that the task employed as the manipulation is inherently exhausting enough to reliably produce ‘depletion’ effects. Recently, a meta-analysis by Dang (2017), has addressed this by systematically investigating the effectiveness of different tasks used as the inhibitory control manipulation. Employing much stricter procedures and addressing issues regarding the inclusion criteria in Carter et al. (2015), Dang demonstrated that so long as the task utilised as the inhibitory control manipulation is experienced as being more mentally exhausting, then it does appear to illicit the subsequently depleting effects observed on behavioural outcomes.

Various inhibitory control tasks have been employed in the literature ranging from highly cognitive tasks such as the colour naming Stroop (e.g. Bray, Martin Ginis, Hicks, & Woodgate, 2008; Dahm et al., 2011; Govorun & Payne, 2006; Hagger et al., 2010; Vohs, Glass, Maddox, & Markman, 2011; Webb & Sheeran, 2003, exp. 1), to those requiring participants to suppress emotions (e.g. Hofmann, Rauch, & Gawronski, 2007; Schmeichel, Vohs, & Baumeister, 2003, exp. 2; Vohs & Heatherton, 2000, exp. 3) and thoughts (e.g. Fischer, Kastenmüller, & Asal, 2012; Vohs & Faber, 2007, exp. 2), or resist the temptation to eat highly desirable foods (e.g. DeWall, Baumeister, Stillman, & Gailliot, 2007; Vohs & Heatherton, 2000, exp. 1 & 2). These tasks most often comprise of a difficult condition requiring high levels of inhibitory control and an easy condition requiring minimal inhibitory control. Some such examples include the emotion video, e-crossing task, attention essay and attention video. During the emotion video (e.g. a video of an animal being harmed) those in the easy (control) condition are told to freely watch the video whilst those in the difficult (experimental) condition are asked to regulate their emotions by supressing or exaggerating their responses. For the e-crossing task, participants are provided with sheets of text and are asked to cross out every letter ‘e’ in accordance with particular rules; In the easy condition participants are asked to cross out every letter ‘e’ whilst those in the difficult condition are asked to cross out every letter ‘e’ unless it is one letter away from or next to another vowel. During the attention essay manipulation, participants are required to write about a particular topic whilst either avoiding the use of common letters such as ‘a’ and ‘n’ in the difficult condition or avoiding the use of uncommon letters such as ‘q’ and ‘z’ in the easy condition. The attention video involves participants watching a video during which stimuli appear on screen; those in the easy condition are simply asked to watch the video whilst those in the difficult condition are told to pay attention to the video, ignoring any stimuli appearing on screen. Dang (2017) reported that the strongest and most reliable of the inhibitory control tasks are the emotion video, attention essay and the Stroop task. In addition, in the case of the e-crossing task (Baumeister et al., 1998), while it was not always experienced as exhausting or effortful, those who did find it so exhibited the expected ‘depletion’ effect on subsequent behaviour. The overriding message in Dang (2017) therefore, is arguably more promising for the self-control literature than that of Carter et al. (2015). Instead of suggesting that the literature is of limited theoretical value, Dang instead highlights the importance of the inherent effectiveness of each inhibitory control task in creating more inhibitory demand and mental exhaustion in order to determine whether or not the resulting findings are meaningful.

One way to determine the effectiveness of the inhibitory task employed in research studies is to include a manipulation check which asks participants to rate how mentally exhausting they felt the task was. These ratings of exhaustion can then be compared between groups in order to ascertain that those undertaking the difficult (experimental) task find it significantly more exhausting than those in the easy (control) condition. This method is common place within the literature (e.g. Bray et al., 2008; Fischer et al., 2012; Friese, Binder, Luechinger, Boesiger, & Rasch, 2013; Friese, Hofmann, & Wänke, 2008; Friese, Messner, & Schaffner, 2012; Govorun & Payne, 2006; Grillon, Quispe-Escudero, Mathur, & Ernst, 2015; Webb & Sheeran, 2003) and is adopted in the four papers presented in this thesis. Here we define mental exhaustion as a psycho-physiological state stemming from sustained mental performance (see van der Linden, Frese, & Meijman, 2003) which is associated with a heightened perception of mental load, feelings of fatigue, inattentiveness and impulsivity (see Kuo & Sullivan, 2001). Mental exhaustion is also thought to contribute to changes in mood, specifically inducing irritability and aggression (see Kuo & Sullivan, 2001). As such in Papers 3 and 4, where emotional lability and variability of valence ratings were crucial dependent variables, it was important to control for any between group differences in emotion which may have stemmed solely from the mentally exhausting nature of the inhibitory task. In order to control for this, participants rated their mood in terms of 5 emotions (happy, sad, angry, aroused, anxious) before and after the inhibitory task. The following section considers how exhaustion arising from inhibitory tasks influences the executive processes responsible for inhibitory control.

The Role of Executive Function in Inhibitory Control

Executive functioning refers to the top-down cognitive processes necessary for working memory, attention, emotion regulation, problem solving and inhibitory control (Miyake et al., 2000; Miyake & Friedman, 2012; Patrick, Blair, & Maggs, 2008), which enable individuals to function in a socially-desirable, organised, and goal-orientated manner (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010; Miyake et al., 2000). Previous research has extensively documented brain regions which appear to be recruited for executive functioning and inhibitory control (Bush, Luu, & Posner, 2000;

De Pisapia, Turatto, Lin, Jovicich, & Caramazza, 2012; Koechlin & Summerfield, 2007; Lenartowicz & McIntosh, 2005); these regions include areas of the PFC and the anterior cingulate gyrus which form the executive attention network and function to monitor and resolve conflicts among cognitive processes by promoting and suppressing the activation of other networks (Botvinick, Braver, Barch, Carter, & Cohen, 2001). These areas have been consistently implicated by inhibitory control tasks such as the Stroop (see Fan, Flombaum, McCandliss, Thomas, & Posner, 2003; Fan, McCandliss, Fossella, Flombaum, & Posner, 2005) reinforcing the notion of their important role in effective inhibitory control and regulation.

Whilst the mechanisms underlying the ‘depleting’ effect of prior inhibitory control are not yet fully understood, it would appear to result from a switch from carefully controlled processing to a reliance on unconscious cognitive processes. More specifically, it appears that when the top-down cognitive capacity necessary to regulate responses, such as the executive attention network, has been implicated (i.e. by the prior use of inhibitory control) there is a switch instead to a reliance on bottom-up processing resulting in behaviour being driven by impulses, desires, and implicit response tendencies (see Bertrams, Baumeister, Englert, & Furley, 2015; Hofmann et al., 2007). Evidence for such an effect is demonstrated in self-control studies which compare performance on Implicit Association Tests following either an easy or difficult inhibitory control task. Such studies have reported higher levels of stereotype consistent responses, as if individuals are relying on automatic implicit attitudes in the absence of adequate cognitive resources needed to inhibit such responses (e.g. Govorun & Payne, 2006). Taken together, these results appear to show that the depletion effect stems from compromised functioning of prefrontal executive control processes. It is interesting to consider those individual differences which might result in a greater susceptibility of inhibitory control processes from prior tasks.

Individual Differences

There are many individual differences which contribute to the successful ability to exert control over automatic implicit responses. Whilst some have documented a positive relationship between individuals' trait levels of self-control and their ability to overcome the 'depleting' effects of prior inhibitory control (Gillebaart & de Ridder, 2015; Muraven, Collins, Shiffman, & Paty, 2005) others have documented the opposite effect (Imhoff, Schmidt, & Gerstenberg, 2014) or failed to find a relationship at all (Stillman, Tice, Fincham, & Lambert, 2009). The Self-Control Scale (SCS; Tangney, Baumeister, & Boone, 2004) is included in the four papers presented in this thesis, in order to further explore evidence either for or against a relationship between trait self-control and the ability to consistently apply control processes to subsequent tasks.

Effective inhibitory control is of upmost importance to healthy cognition. Those with lower levels of self-control are found to engage in more health risk behaviours (Wills, Isasi, Mendoza, & Ainette, 2007) and report higher rates of psychopathological symptoms associated with depression, anxiety, obsessive-compulsive disorder, phobias and paranoia (Tangney et al., 2004), see de Ridder, Lensvelt-Mulders, Finkenauer, Stok, & Baumeister (2011) for a meta-analysis. One factor which affects the incidence of such symptoms is emotion regulation.

Emotion Regulation and Inhibitory Control

Emotion regulation is a facet of inhibitory control which enables individuals to manipulate the original trajectory of their emotional response as a means to respond in a more socially desirable, adaptive, or beneficial manner. Whilst emotion regulation often happens on an unconscious, automatic basis, changes to the emotional response can also happen through the conscious recruitment of strategies such as, biting one's tongue or breathing deeply (see Gross, 2015). Emotional stability and inhibitory control are highly correlated (Tangney et al., 2004) with those individuals exhibiting high levels of control, experiencing less intense moods with fewer fluctuations (Layton & Muraven, 2014). As previously discussed, the emotion video which requires high levels of emotion regulation, is one of the most effective 'depleting' inhibitory control tasks (see Dang, 2017) and is often employed in the literature (e.g. Hofmann et al., 2007; Schmeichel et al., 2003, exp. 2; Vohs & Heatherton, 2000, exp. 3).

For most individuals, emotion regulation happens automatically (Volokhov & Demaree, 2010) however in the absence of the means needed to successfully regulate responses, emotions can maladaptively bias cognition. Individuals with low levels of control show poorer inhibition of negative emotions (Kieras, Tobin, Graziano, & Rothbart, 2005). Interestingly, but perhaps not unsurprisingly, many disorders characterised by a lack of inhibitory control are linked with failures in emotion regulation (Eftekhari, Zoellner, & Vigil, 2009) such as anxiety (Cisler & Koster, 2010; Cisler & Olatunji, 2012), Bulimia Nervosa (Anestis et al., 2009), and Attention Deficit Hyperactivity Disorder (ADHD; Skirrow et al., 2014; Walcott & Landau, 2004). Therefore, the importance of examining the influence of states of inhibitory control (whether depleted or not) on processing in both clinical and non-clinical populations remains an important endeavour in order to better understand processing in those suffering from disorders characterised by persistently low levels of self-control.

Another facet of research directly related to the inhibitory control literature and thought to similarly effect emotion regulation, and cognition and behaviour in general is cognitive load theory which is discussed further below.

Cognitive Load versus Inhibitory Control Depletion

Cognitive load theory, developed by Sweller (1988), is built on Atkinson and Shiffrin's (1968) model of information processing comprising of working, long-term, and sensory memory stores. Cognitive load specifically concerns working memory, also known as short-term memory, which refers to the cognitive ability to process and consciously manipulate information (Maranges, Schmeichel, & Baumeister, 2017). Working memory is used for language comprehension and problem solving among other executive processes (Cowan, 2010) and is thought to predict cognitive performance on a variety of tasks such as the Stroop, antisaccade, and dichotic-listening task (Engle, 2002). Miller (1956) claimed that working memory can only hold up to around seven pieces of information (e.g. numbers, letters, or words) at one given time. Whilst the exact limit and nature of the capacity is still under enquiry, researchers are in agreement that working memory has a limited capacity which can only hold up to around 3-5 chunks of information at a time (Farrington, 2011; Halford & Andrews, 2009), see Cowan (2010) for a review. Due to its limited capacity, tasks relying on working memory impose what it is termed ‘cognitive load’ which can impede performance on other tasks requiring executive function (Ariely, 2000) resulting in for example, increased antisaccade task reaction times and errors (Berggren, Hutton, & Derakshan, 2011; Engle, 2002) and greater distractor interference (Dalton, Santangelo, & Spence, 2009). As a result of cognitive load, individuals exhibit a tendency to rely instead on implicit modes of thought and long-term schematic information (Ariely, 2000; Drolet & Luce, 2004; Greene, Morelli, Lowenberg, Nystrom, & Cohen, 2008).

There are many parallels between the effect of inhibitory control induced ‘ego-depletion’ and cognitive load, not least the fact that both states appear to reduce the resources available to successfully perform a secondary task requiring carefully controlled cognitive processes. Interestingly, Diamond (2013) stresses that working memory and inhibitory control processes actually support each other. For instance, individuals must be able to use working memory to keep goals in mind to exert inhibitory control and act in a goal-directed manner; likewise, individuals must be able to recruit inhibitory control to supress irrelevant information in order to free up working memory for the task at hand (Diamond, 2013). Despite this Maranges et al. (2017) directly compares the two and highlights differences pertaining to the onset, recovery-time, and task specificity of, the state of reduced cognitive control. Crucially, cognitive load effects performance on concurrent tasks, while depletion influences performance on a secondary task after the prior exertion of inhibitory control. Furthermore, cognitive load can affect performance on any task requiring the use of working memory (Lavie, Hirst, De Fockert, & Viding, 2004) whilst depletion appears to only effect tasks requiring some vestige of inhibitory control and does not affect working memory (see Maranges et al., 2017 for a full comparison).

When comparing the effects of cognitive load and prior inhibitory control on emotion regulation, research is less conclusive. The prior exertion of inhibitory control impairs effective emotion regulation resulting in increased amygdala activation (Wagner & Heatherton, 2013). Whilst some researchers suggest cognitive load appears to prevent the full processing of emotional stimuli which results in decreased amygdala activation and less influence on subsequent behaviour (Drolet & Luce, 2004; Maranges et al., 2017; Van Dillen, Heslenfeld, & Koole, 2009), others have reported a greater reliance on emotion as a source of information under periods of high cognitive load (Schwarz, Strack, Kommer, & Wagner, 1987; Siemer & Reisenzein, 1998), this is referred to as the mood-as-input hypothesis and is explained further below.

Mood-as-Input

The mood-as-input hypothesis explains individuals' decisions to stop or continue at a task in terms of an interaction between their stop rules (e.g. 'as many as can' or 'feel like continuing') and information about whether they have met their goals, for which their current mood is used as a source of information (see Meeten & Davey, 2011, for a review). The hypothesis has been used to successfully explain perseverative behaviours such as depressive rumination (Hawksley & Davey, 2010; Watkins & Mason, 2002), catastrophic worrying (Startup & Davey, 2001, 2003) and perseverative checking (Benie MacDonald & Davey, 2005). Mood is more likely to be used as information when the individual does not have access to other sources of information such as expertise (Forgas & Tehani, 2005), and less likely to be used where the source of their mood is salient and believed to be irrelevant to the task at hand (Schwarz & Clore, 1983). Cognitive load theory is known to influence this effect; as cognitive load increases, individuals are more likely to attend to their mood and use it as a source of information (Schwarz et al., 1987; Siemer & Reisenzein, 1998). This intensifies during a state of negativity where individuals have a greater desire to understand and repair their mood (see Schwarz & Clore, 1983). Whilst it is less clear whether inhibitory control depletion has the same effect, it is feasible that mental exhaustion arising from the prior use of inhibitory control might result in a higher tendency to rely on mood as a source of information. Thus, individuals might be more sensitive to mood manipulations following a prior inhibitory task which is cognitively demanding, especially if the task itself has induced some degree of negative state such as those associated with exhaustion (e.g. anger or irritability).

Unconscious Processing

An important question which underlies each of the papers presented in this thesis is whether mental exhaustion arising from the prior use of inhibitory control leaves us more susceptible to unconscious influences. Unconscious influences have been of enduring interest in psychological research relating to emotion, attention, decision making, motivation and attitudes. However, one of the greatest complications in the study of cognition and behaviour in terms of consciousness lies in the ability to empirically distinguish when an individual has, or does not have, conscious awareness (Schooler, Mrazek, Baird, & Winkielman, 2015).

Consciousness can be referred to as the "subjective status" of mental content such as thoughts, feelings or perception (Schooler et al., 2015). One school of thought adopts an 'all-or-none' view of conscious perception suggesting that the distinction between the unconscious and conscious is a clear dichotomy (Sergent & Dehaene, 2004). However, such an account fails to determine the characteristics of conscious content. Just because one is consciously able to report seeing a flash of some kind of stimulus does not mean that they are consciously aware of the content of that stimulus. For example, in a word priming paradigm, where words are presented subliminally before a judgment must be made regarding the nature of the word, one might be aware of seeing a masked stimulus but not be able to correctly categorise it as either a word or a non-word. In this case, according to a dichotomous account, an individual would be thought to have conscious awareness despite them having no conscious recollection or awareness of the content of the stimulus itself. Due to numerous states of awareness which are difficult to classify as either purely unconscious or conscious, consciousness can also be viewed as a gradient (see Norman, 2010).

Further Schooler et al. (2015), suggest that levels of consciousness can be determined in relation to at least three characteristics: (1) a genuine unawareness, (2) awareness without meta-awareness, and (3) genuine meta-awareness. Here meta-awareness refers to an individual's knowledge about their own awareness. For example, being able to self-reflect on their awareness of a particular stimulus or the effect that it is having on them. The authors stress that these three categories are not exhaustive and that other distinctions are highly possible. In support of these characteristics, Dienes and Scott (2005) define unconscious knowledge as knowledge an individual has despite not being conscious of having it (i.e., an awareness in the absence of meta-awareness). Much research now endorses the use of confidence ratings, where participants report whether they are guessing or have a degree of confidence in their judgement, to establish levels of unconscious knowledge (see Dienes, Altmann, Kwan, & Goode, 1995; Dienes & Scott, 2005). Here, the absence of conscious knowledge of subliminally presented stimuli is indicated by a lack of confidence despite being able to correctly discriminate between stimuli (see Scott, Samaha, Chrisley, & Dienes, 2018). Such research suggests that consciousness can be defined by a series of dichotomies that distinguish between the conscious content of the experience. That is, each trial can be followed by a series of dichotomous judgements which enable researchers to distinguish between conscious and unconscious knowledge. For example, 'Did you see anything? (yes or no)', 'Did you see a word or non-word? (word or non-word)', 'Do you have any confidence in your judgment? (some confidence or guessing)'. If an individual is able to classify strings as either a word or non-word with above chance accuracy but report that they are guessing it is thought to be unconscious in the sense that they appear to have awareness without meta-awareness.

GENERAL INTRODUCTION

There is a wealth of research documenting the effects of a variety of unconscious influences on behaviour and cognition. Research postulates that mental content can be consciously experienced without any mindful reflection about the effect of that content on an individual's own cognition, emotion, perception, or behaviours (i.e. such as failing to recognise your emotional state until someone asks you to reflect upon it) or lacking in any conscious awareness of the cause of the emotional reaction (Damasio, 1995). Interestingly, research shows that an individual who gains meta-awareness of a pleasant feeling or emotion, is less likely to enjoy it or feel positively about it than an individual who has no explicit meta-awareness of their mood state (Schooler, Ariely, & Loewestein, 2003). Emotionally valenced subliminal primes (such as positive or negative words) have been shown to unconsciously influence subsequent evaluations of stimuli in the absence of any conscious awareness. For example, Custers and Aarts (2005), used an evaluative conditioning paradigm to demonstrate that subliminally presenting an activity (e.g. "reading") alongside a positive word, increased the rated appeal of that activity in comparison to those that were paired with a neutral word. Similarly, Strahan, Spencer, and Zanna (2002), reported an unconscious influence on an indirect measure of mood, namely that a subliminally presented sad or neutral face altered individuals' ratings of a subsequently presented piece of music such that those who had been unconsciously presented with the sad face rated the music as more sad than neutral controls. Research has repeatedly reported that subliminal priming can activate and facilitate goal pursuit (cf. Bargh, Lee-Chai, Barndollar, Gollwitzer, & Trötschel, 2001; Dijksterhuis & Aarts, 2010, with Pashler, Coburn, & Harris, 2012) and can influence attention in the absence of conscious awareness (see Jiang, Costello, Fang, Huang, & He, 2006). In terms of implicit learning, research shows that individuals are able, with above chance accuracy, to apply implicitly learnt rules in the absence of a conscious ability to verbalise knowledge of the structure of these rules (Dienes & Scott, 2005). Such findings further reiterate the existence of intermediate levels of awareness which cannot be easily categorised as either purely unconscious or conscious (see Dienes & Scott, 2005; Norman, Price, Duff, & Mentzoni, 2007).

For the purpose of this thesis we take the unconscious to be an absence of meta-awareness; for example, where there is a dissociation between subjective reports and influence on behavioural measures. Whilst Paper 1 is arguably the most direct test of unconscious processing, the subsequently presented papers examine influences which are either experienced as subjectively non-volitional (e.g. hypnosis, Paper 2), or have an impact on emotion regulation, a process which is thought to often be elicited in the absence of subjective awareness or meta-awareness of a particular mood state (see Koole & Rothermund, 2011). Further, whilst individuals might be aware of their mood state, they could remain unaware of the cause of that change in emotion (Paper 3) or the effect it has on subsequent responses (Paper 4).

Summary and Rationale

Previous research has documented the effect of challenging inhibitory tasks on subsequent self-regulatory behaviour that would typically be considered under conscious control; the effect of such influences has been shown to result in a variety of negative behavioural outcomes (see Fischer et al., 2012; Vohs & Faber, 2007; Vohs & Heatherton, 2000). The four papers presented in this thesis explore whether the effects of prior inhibitory challenge extend beyond conscious outcomes to include unconscious influences on cognition and behaviour. This research will help to determine the extent to which impeded self-control, observed to occur after an inhibitory task, arises not simply from conscious disinhibition but from a greater susceptibility to unconscious influences.

Paper 1 examines the effect of a difficult prior inhibitory control task in comparison to an easy task on subsequent susceptibility to unconscious priming of neutral (Experiment 1) and reward (Experiment 2) words in a stem completion paradigm. Whilst the inhibitory control manipulation proved effective, with the difficult task being rated as significantly more exhausting, neither the degree of inhibitory challenge nor trait self-control influenced subsequent susceptibility to unconscious priming for either neutral or reward salient stimuli. Bayesian analysis provided strong evidence that this was a sensitive null effect and thus that the experienced mental exhaustion did not increase susceptibility to unconscious priming.

Considering these findings, Paper 2 explores whether the prior use of inhibitory control might have an effect on subsequent susceptibility to an alternative source of unconscious influence, namely hypnosis. Here, participants completed either an easy or difficult task before their responsiveness to four hypnotic suggestions was evaluated. Again, the inhibitory control task was experienced as more mentally exhausting. However, the results provide substantial evidence that the prior exertion of inhibitory control does not influence subsequent susceptibility to hypnotic suggestion.

Paper 3 investigates emotion regulation, a facet of human behaviour which although conscious, is moderated by unconscious influences, following prior inhibitory control. Specifically, this paper compares mood lability in response to a mood induction (via music) following either an easy or difficult inhibitory task in a behavioural (Experiment 1) and fMRI imaging (Experiment 2) design. Experiment 1 demonstrated that participants found the difficult inhibitory challenge more exhausting and provides strong evidence that the prior use of inhibitory control results in a period of increased emotional reactivity. Due to data insensitivity the behavioural results from experiment 2 were unable to provide evidence for or against any effect of the inhibitory control manipulation on subsequent mental exhaustion and mood lability. Whilst the fMRI results showed significant clusters of activation in the hypothesised networks (default mode and executive control networks), after the inhibitory task, this was only observed when the results were collapsed across task condition. Thus, the results were unable to provide evidence relevant to an effect of prior inhibitory control on cortical activity and resting-state network connectivity.

Paper 4 examines, in Experiment 1, whether the period of heightened mood lability following prior inhibitory control (observed in Paper 3), would be reflected in individuals' emotion ratings of positively and negatively valenced stimuli. Conversely, Experiment 2 investigates whether a brief mindfulness manipulation, reported to increase capacity for emotion regulation, would reduce the severity of emotional response reflected in individuals' ratings of the same set of positively and negatively valenced stimuli. Whilst the inhibitory control task in Experiment 1 was again experienced as significantly more exhausting, the manipulation of inhibitory challenge had no effect on subsequent extremes of emotion attributed to images. Similarly, in Experiment 2, whilst the mindfulness manipulation and mind-wandering control condition elicited equivalent engagement, there was no effect on subsequent extremes of emotion ratings.

Taken together, the research presented in this thesis provides the novel contribution that despite the mental exhaustion arising from prior inhibitory control, such tasks appear to have no effect on subsequent susceptibility to unconscious influences arising from unconscious priming or hypnosis, and no effect on the emotion attributed to valenced stimuli. Whilst mental exhaustion arising from the prior use of inhibitory control does appear to result in a period of increased mood lability, limitations in the inhibitory control manipulation when applied in an fMRI context means that we are unable to draw conclusions relating to whether these effects are supported by changes in neural activation or resting-state connectivity.

Paper 1:

Susceptibility to Unconscious Influences is Unaffected by a Challenging Inhibitory Task or Mental Exhaustion

Angela Gurney, Anna-Nepheli L. Lagos, Abigail Manning, Ryan B. Scott

University of Sussex

Author Note:

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AG designed the experiments with RS's oversight. AG ran the studies with assistance in data collection from two undergraduate students (ANL and AM). The analysis and write up were completed by AG with comments and advice on the manuscript provided by RS.

Abstract

Unconscious influences have been demonstrated in a variety of behavioural contexts, however, a key question remains – to what extent do such influences vary with our changing mental states? We examine whether a prior inhibitory challenge increases susceptibility to subliminal priming in a stem completion task employing neutral (Experiment 1) and reward salient terms (Experiment 2). Results show stem completions to be significantly influenced by unconscious priming, and the challenging inhibitory task (the Stroop) to be significantly more mentally exhausting than the control task. However, neither the degree of inhibitory challenge, trait self-control, nor task-related mental exhaustion significantly influenced unconscious priming. Bayesian analysis provides strong evidence that prior inhibitory challenge does not affect susceptibility to unconscious priming. The study supports the conclusion that unconscious processing can be independent of consciously experienced mental states and provides reassurance that inhibitory impairment, common to mood disorders, should not increase susceptibility to unconscious influences.

Keywords: Inhibitory control; self-control; unconscious; subliminal priming

Human susceptibility to unconscious influences has been of enduring interest in both lay and research contexts since the earliest psychological endeavours. An extensive literature exists demonstrating the effects of unconscious priming in various forms on a variety of behavioural outcomes (e.g. Kiefer, 2002; Klauer, Eder, Greenwald, & Abrams, 2007). An important question that is largely unexplored in this context however, is the extent to which such influences vary with our changing mental state – are we more susceptible to unconscious influences when tired or exhausted from prior mental exertion? Gauging the extent of such variations could be especially important to understanding how unconscious influences contribute in a variety of clinical conditions characterised by chronic mental fatigue and impaired inhibitory control. Those with low levels of self-control suffer from poorer inhibition of negative emotional responses (Kieras et al., 2005), engage in more health risk behaviours (Wills et al., 2007) and report higher levels of psychopathological symptoms including those linked to depression, anxiety, obsessive-compulsive disorder, phobias and paranoia (Tangney et al., 2004), see de Ridder, Lensvelt-Mulders, Finkenauer, Stok, and Baumeister (2011) for a meta-analysis. Thus, with control being paramount to a healthy human psyche, it is important to better understand how those suffering from mental fatigue might be differentially affected by unconscious influences.

Hypnotism and evolutionary theory are often credited as being the first allusions to the unconscious, but it was Pierce and Jastrow (1884) who were the first to empirically study subliminal perception and to report the ability to distinguish between different stimuli, even in the absence of conscious awareness. Another early account of subliminal priming comes from Sidis (1898), who presented participants with small cards printed with a single number or letter, at a distance from which they reported being unable to decipher the stimuli. Despite reporting being unable to consciously perceive the stimuli, Sidis discovered that when tested using a forced choice paradigm, the participants guessed the cards' contents correctly at above chance, suggesting some level of unconscious perception. Although it became a popular topic of research (see Adams, 1957, for a review), subliminal priming received much criticism from claims that there was a need for a higher level of certainty about participants' awareness of primes or the implementation of a confidence criterion (Eriksen, 1960).

Cheesman and Merikle (1984, 1986) distinguished between objective and subjective thresholds of conscious awareness. The objective threshold is defined by the level at which performance in some discrimination is objectively at chance. In contrast, the subjective threshold more directly taps the phenomenal experience and is defined by that level at which participants believe they are unable to discriminate the stimuli regardless of whether they actually show above chance accuracy (Jack & Shallice, 2001; Merikle, Smilek, & Eastwood, 2001). The subjective threshold demonstrates a lack of meta knowledge in the sense that participants either truly believe they are guessing or show no correlation between their confidence and accuracy, referred to respectively as the 'guessing criterion' and 'zero correlation criterion', (Dienes, Altmann, Kwan, & Goode, 1995). There has been considerable evidence for priming below the objective threshold, however for the most part effects have been smaller, hard to attain and short lived (e.g. Draine & Greenwald, 1998; Klauer et al., 2007, though cf. Van den Bussche, Van den Noortgate, & Reynvoet, 2009, for a meta-analysis of subliminal priming effects who report no significant effect of using objective versus subjective thresholds). In the present study, where the central purpose is to assess whether different mental states might affect our susceptibility to unconscious influences, it is important that we attempt to adopt the most sensitive of measures; for this reason, we adopt a subjective threshold in identifying participants unconscious thresholds.

One of the enduring paradigms for the study of unconscious influences, is the stem completion task (see Graf & Mandler, 1984). This task involves presenting a word prime for a duration too brief to be consciously discerned and then requiring the participant to complete three letters (a word stem) to form the first word that comes to mind. Typically, the word stem could be completed to form the subliminally presented word as well as multiple alternatives. For example, for the prime ‘reliable’, the stem would be ‘rel’ and possible completions would include ‘reliable’, ‘relevant’, ‘relax’ etc. Valid inferences from a stem completion task clearly depend on each stem having an appropriate minimum number of alternate completions (Soler, Dasí, & Ruiz, 2015). Studies have consistently demonstrated that when participants report being unable to read the prime (i.e. it is below their subjective threshold), it nonetheless influences their subsequent choice of word completion (Perrig & Eckstein, 2005; Tiggemann, Hargreaves, Polivy, & McFarlane, 2004). The stem completion paradigm has been employed extensively to study implicit learning (Fleischman et al., 2005), lexical memory (Nelson, Keelean, & Negrao, 1989) and memory related individual differences (Lorenzi, Giunta, & Di Stefano, 2006). The present study exploits the stem completion task to index how the degree of subliminal priming differs across task conditions.

When exploring the potential effect of mental states on susceptibility to unconscious influences, a relevant literature is that which has sought to examine the effect of mental exertion on conscious behaviours. This has predominantly been explored in the context of research seeking to manipulate self-control. Such research has employed a dual-task paradigm to evaluate the extent to which exerting inhibitory control on an initial task affects the degree of control applied to subsequent tasks. Prior inhibitory tasks have been reported to influence subsequent behaviour in a variety of different ways, for example resulting in overeating (Hofmann et al., 2007; Vohs & Heatherton, 2000), increased risk-taking (Fischer, Kastenmüller, & Asal, 2012), aggression (DeWall et al., 2007), impulse buying (Vohs & Faber, 2007), and more frequent stereotypical judgments (Govorun & Payne, 2006), see Hagger, Wood, Stiff, & Chatzisarantis, 2010, for a meta-analysis.

Some accounts of the effects of mental exhaustion on subsequent behaviour have proven to be controversial, with the resource model (Baumeister et al., 1998) having been especially subject to challenge. This model proposes a reliance on a limited pool of resources which is depletable with use and, once used, takes time to replenish (Baumeister & Vohs, 2007). When in this depleted state subsequent attempts at self-control are thought to be impaired (Baumeister et al., 1998). However, attempts to characterise the resource as blood glucose (Gailliot et al., 2007; Masicampo & Baumeister, 2008) have been vigorously challenged (Beedie & Lane, 2012; Job et al., 2010; Kurzban, 2010; Martijn et al., 2002; Schmeichel & Vohs, 2009; Tice et al., 2007) and without an identifiable resource the model is of limited theoretical value (Kurzban et al., 2013). A recent meta-analysis (Carter et al., 2015) and a registered replication report (Hagger et al., 2016) also further challenge this conceptualisation. Nevertheless, new research has demonstrated that as long as inhibitory control tasks, such as those employed in the self-control literature (e.g. the colour naming Stroop), are experienced as being more mentally exhausting, they do appear to impact upon further attempts at self-control (Dang, 2017). The Stroop task was identified by Dang as amongst the strongest and most reliable of the self-control tasks used to induce a state of mental exhaustion and is therefore adopted in the present study as our inhibitory control manipulation.

Despite the enduring belief that trait levels of self-control protect, and are positively correlated with, an individual's ability to overcome the depleting effects of prior exertion of self-control (Gillebaart & de Ridder, 2015; Muraven et al., 2005), some studies have reported a negative correlation between the two (Imhoff et al., 2014) or have failed to find any effect at all (Stillman et al., 2009). Therefore, in order to further explore and control for any relationship between trait levels of self-control, and the use of inhibitory control processes during periods of mental fatigue, we include the Self-Control Scale (Tangney et al., 2004) in the present study. In spite of the challenges encountered by attempts to model self-control, interesting questions remain regarding the effect of mental exhaustion on subsequent unconscious processing.

A large body of research indicates that when adequate cognitive capacity is available, behaviour will be predominantly driven by explicit and controlled processes. However, in situations where this capacity is unavailable, behaviour will be driven by impulses, attitudes, and implicit response tendencies (Hofmann et al., 2007), as the lack of cognitive capacity leads to an inability to inhibit such responses and a reliance on automatic bottom-up processing (Bertrams, Baumeister, Englert, & Furley, 2015). Indeed, whilst perceiving, storing, and retrieving information appears to happen automatically (Schmeichel, Vohs, & Baumeister, 2003), inhibiting responses appears to decrease mental efficiency on subsequent executive functions such as reading comprehension, working memory and response inhibition (Stucke & Baumeister, 2006). This switch to automatic implicit response tendencies is notably demonstrated in studies employing Implicit Association Tests which have shown that after completing a demanding inhibitory control task, participants are more likely to be guided by their automatic attitudes and make more stereotype consistent errors on racial discrimination tasks (e.g. Govorun & Payne, 2006). Furthermore, in a colour priming study, Bertrams et al. (2015) demonstrated that those who had previously completed a task high, versus low, in the need for self-control were more susceptible to the negative effect of being primed with the colour red. Specifically, participants completed one of two versions of a writing task that involved either directly copying some text or reproducing it with specific changes such as omitting the letter e and including deliberate misspellings. They were then primed with the word 'test' on either a red or grey background prior to completing a mental arithmetic evaluation. The red colour priming effect of decreased arithmetic performance was only seen for those who had previously exerted high levels of inhibitory control. However, the approach adopted by Bertrams et al., utilised consciously presented colour blocks as their priming methodology. As such, findings from the study cannot be conclusively attributed to unconscious influences.

Understanding whether mental fatigue increases our susceptibility to unconscious influences is important from a theoretical standpoint and has potentially important practical implications. In the present study, we specifically examine unconscious priming achieved through subliminal word presentation. Here we examine whether the effects observed in conscious contexts extend to unconscious influences. Specifically, we test for the first time whether a prior inhibitory challenge increases susceptibility to unconscious priming and whether this varies with the emotional salience of primes. The degree of prior inhibitory challenge is manipulated by the completion of either an easy or difficult version of a colour classification task, the Stroop task. The effect of this manipulation is then examined on the extent to which unconscious priming influences responses in a stem completion task. Experiment 1 examines how a prior inhibitory challenge effects the priming for neutral terms. We predict that participants in the difficult condition will be more susceptible to unconscious priming and thus will complete more stems with the primed words.

Experiment 2 then contrasts the effect for neutral and reward salient terms i.e. those relating to food and drink. We predict that a challenging inhibitory task increases subsequent susceptibility to unconscious influences. Thus, those in the challenging task condition will complete more stems with the primed target word especially those of a reward relevant nature.

Experiment 1

Method

Participants

Participants were 60 volunteers (33 female, 27 male) aged 18-29 years (*M* = 20.75, *SE* = 1.79) recruited from the University of Sussex and participating in exchange for entry into a £25 prize draw. Participants were naïve to the experimental hypothesis and were randomly assigned in equal proportions to one of two inhibitory task conditions: inhibitory challenge vs. control. All participants were native English speakers. The experiment was considered low risk and received ethical approval from the University of Sussex School of Psychology ethics committee. All participants read an information sheet and signed a consent form before the experiment began. At the end of the experiment participants were fully debriefed as to the nature of the experimental aims.

Materials

The controlling program was implemented in Matlab, run on a Pavilion DM4 computer with a 15” 60Hz monitor. Participants were seated with a viewing distance of 600mm. The complete set of materials for both experiments and the corresponding data has been made publicly available on the Open Science Framework (OSF) and can be retrieved from https://osf.io/gphkq/.

The threshold finding task and stem completion task used distinct sets of words. The threshold finding task used ten colour names and the numbers one to twenty. These highly familiar words were used on the basis that the threshold for their detection would be lower than that for the less familiar terms used in the stem-completion task. The stem completion task utilised a list of 100 target words compiled from the British National Corpus online service. No two words began with the same three letters and these three letter stems (e.g. ‘bis’ for ‘biscuit’) had at least two possible alternative real word completions (e.g. bishop or bisect). Non-words for both the threshold finding task and stem completion task consisted of random sequences of consonants, matched in length to the target words. See Appendix A for a full list of the word stimuli used in the experiment. Words and non-words were displayed in ‘Courier New’ font size 30 and were light grey (0.8 on a scale of 0-1 where 0 = black and 1 = white), with a luminance of 63.78 cd/m^2 and contrast of -0.36, presented on a white background with a luminance of 99.68 cd/m^2. The mask was 40 by 180 mm (large enough to obscure the largest word used) and comprised randomized patterns of black and white 3-pixel by 3-pixel blocks. Masks had a maximum luminance of 99.68 cd/m^2, a minimum luminance of 0.09 cd/m^2 and a contrast of -0.99.

The full 36 item Self-Control Scale (SCS; Tangney et al., 2004) was included as a self-report measure of trait self-control.

Design

The experiment utilised a mixed design with two independent variables: inhibitory task (between subject: challenge vs. control) and priming (within subject: target word vs. non-word). The primary dependent variable was the number of stems completed with the target word. The measure of trait self-control provided by the SCS was included as a covariate.

Procedure

The experiment was conducted in a quiet room with the experimenter present at all times. All instructions were given on screen and clarification was provided by the experimenter when required. Participants provided demographic information (age and gender) before beginning the experimental tasks. Each of the experimental tasks, in the order they were completed, are outlined below.

Visual threshold task. This established individual visual thresholds in order to ascertain that primes in the stem completion task were presented below the subjective threshold of conscious awareness. Each trial involved the presentation of a word or non-word with every four trials including two of each in random order. Trials began with a fixation cross presented in the centre of the screen for 1000ms. The black and white mask then appeared in the centre of the screen for 600ms. The target was then presented for the same duration before the mask was again presented for a further 600ms. Participants were then presented the question 'Do you think there was a real word or a non-word?' and their response captured using the arrow keys. A second question, 'Do you have any confidence in your judgement?' alongside the options 'some confidence' and 'guess', was then displayed. They were instructed to indicate having 'some confidence' even if they had only the tiniest amount.

Initially, every trial correctly classified and made with 'some confidence' resulted in a 50ms reduction in the duration that the target was presented on subsequent trials (the mask duration of 600ms remained unchanged throughout). These reductions continued until the participant reported 'guessing', after which the duration of exposure was increased to that of the previous trial and the subsequent reductions after correct confident trials reduced to 16.67ms (a single screen refresh). Hence, the subjective unconscious threshold was always approached in steps of a single screen refresh. When participants reported that they were guessing for 6 consecutive trials at the same exposure duration that duration was taken to be their subjective unconscious threshold and the task ended.

Inhibitory control manipulation. Participants completed one of two versions of a colour naming task (inhibitory challenge vs. control). Those in the inhibitory challenge condition completed a four-colour Stroop task requiring them to classify the colour in which one of the words red, blue, green or yellow were written while suppressing the tendency to respond based on the word itself. For example, 'red' written in blue was to be classified as blue and not red (the four text colours used were also red, green, blue and yellow). Participants were instructed to be as accurate as possible and keep errors to an absolute minimum. Each trial began with a fixation cross for 300ms before the colour word was presented for 1000ms. Words were displayed in 'Arial' font size 50. Classifications were made using the number keys 1-4 with their corresponding colours shown onscreen in monochrome. If participants failed to respond within one second or a wrong classification was made, then an error tone (middle C pitch) sounded. Every eight trials contained two trials of each colour word in a randomized order, with a total of 240 trials. For six out of every eight trials the colour word and the text in which it was written were the same (concordant trials), for the remainder the colour words were written in one of the other three colours chosen at random (discordant trials).

Those in the control group completed a simplified colour classification task that did not require any inhibition. Specifically, only two colour words were presented (red and green) and the text colour was always congruent with the word. No time limit was imposed however the error tone still sounded if a mistake was made. The duration of the control condition was fixed to match that of the inhibitory challenge condition, irrespective of the number of trials completed. The colour classification task was followed by a 1-minute break during which a countdown timer was presented on-screen.

Stem completion task. For each participant, the primes consisted of a randomly selected 50 of the 100 target words together with the length-matched non-words for the other 50 target words. The order of word and non-word trials was randomised over participants. Each trial consisted of the following: a fixation cross presented in the centre of the screen for 1000ms, followed by a forward mask for 600ms, followed by the word or non-word prime for the individual's threshold duration, followed by a backward mask for 600ms. A question mark then appeared in the centre of the screen to which participants had to respond either 'Y' for yes if they thought they had seen the prime or 'N' for no if they did not. Where the participant responded with 'Y' they were presented with a screen prompting them to type in what they believed they saw and to press enter to move to the next trial; note no stem completion was conducted where they believed they had seen a prime. Where the participant responded with 'Y' and correctly identified the prime, then the prime exposure duration was reduced by 16.67ms for subsequent trials. If the participant chose 'N' they were given the 3-letter stem corresponding to the target word with the instruction to complete it with the first word that came to mind. Participants were given 10 seconds to respond before a warning tone was played and a message to please hurry presented on-screen. Participants were encouraged to report any targets they thought they saw and incentivised to do so by the provision of a bonus for any correctly identified. Thresholds ranged from 85 to 187ms (M = 131.33ms, SE = 3.19ms). A complete list of individual thresholds can be found in the data file provided on the OSF.

Rating of mental exhaustion. A single screen was displayed with the question 'Thinking back to the earlier colour classification task, how mentally exhausting did you find it?' Responses were recorded on a VAS scale ranging from 'Not at all' (1) to 'Extremely' (600).

Self-control questionnaire. Finally, participants completed the Self-control Scale using keys 1 to 5 on the keyboard to correspond to the five-point Likert scale ranging from 1 ('not at all') to 5 ('very much').

Results

Inhibitory Control Induced Mental Exhaustion

An independent t-test revealed that participants in the inhibitory challenge condition rated the inhibitory task as significantly more mentally exhausting (M = 369.20, SE = 23.53) than those in the control condition (M = 198.03, SE = 31.94), $t(51.89) = -4.31$, $p < .001$, $d = 1.13$.

The Effect of a Prior Inhibitory Control Challenge on Unconscious Priming

A 2 (inhibitory task: challenge vs. control) x 2 (priming: word vs. non-word) mixed ANOVA was conducted on the percentage of stem completions that matched the target word (target matches), see Figure 1. The analysis revealed a significant main effect of priming, $F(1, 58) = 6.43$, $p = .014$, $\eta_p^2 = 0.10$, no significant main effect of inhibitory task, $F < 1$, and no significant interaction, $F < 1$. The effect of priming reflected a significantly greater number of target matches for the word versus the non-word priming condition.

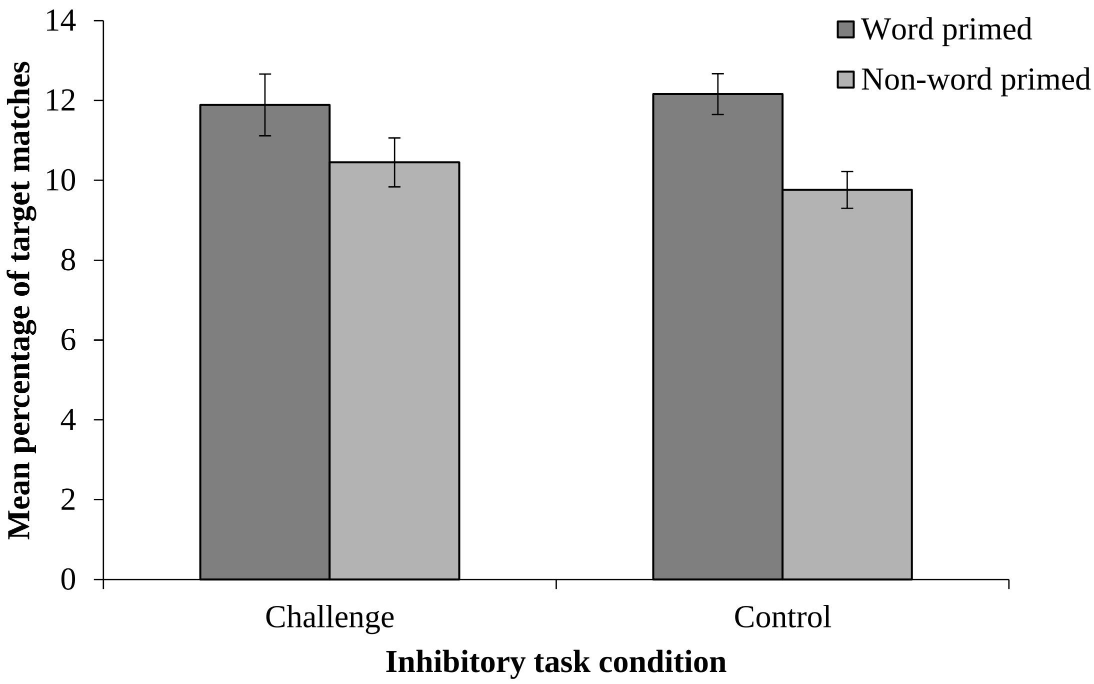

Figure 1. Mean percentage of stem completions that matched the target word by priming and inhibitory task condition (+/- 1 SEM)

A Bayes analysis on the effect of the inhibitory task was conducted to establish the extent to which this data provides evidence for the null hypothesis, namely that a prior inhibitory challenge has no effect on susceptibility to unconscious priming. Adopting the procedure advocated by Dienes (2014), we specified the prior as a uniform distribution from zero to twice the effect observed in the control condition. The resulting Bayes factor of 0.25 is less than one third and thus represents strong evidence for the null hypothesis.

The Effect of Trait Self-Control and Mental Exhaustion on Unconscious Priming

To evaluate the potential effects of trait self-control and mental exhaustion on unconscious priming the above ANOVA was repeated with SCS and reported task-related mental exhaustion included as covariates. Neither covariate achieved significance, all $F < 1$.

Discussion

Experiment 1 aimed to investigate the effect of a prior inhibitory task on subsequent susceptibility to unconscious priming using a stem completion paradigm. Consistent with the established literature (Perrig & Eckstein, 2005; Tiggemann et al., 2004) the stem completion task revealed a significant sensitivity to unconscious priming. The inhibitory task was also rated by participants to be significantly more mentally exhausting than the control task, suggesting that it was successful in creating greater inhibitory demand. However, the prior inhibitory challenge was not found to influence the degree of susceptibility to unconscious priming, with a Bayes analysis indicating that this was a sensitive null result. Similarly, neither trait self-control nor task-related mental exhaustion were found to significantly influence unconscious priming.

Our findings contrast with those of previous studies examining the effects of prior inhibitory challenge on responsiveness to consciously perceived environmental cues (Govorun & Payne, 2006). However, aside from the fact that the cues were presented consciously, these studies predominantly examined the response to emotional or reward salient items, such as food and drink (e.g. Papies & Hamstra, 2010; Papies, Stroebe, & Aarts, 2008). This highlights the possibility that our failure to observe an effect of the prior inhibitory challenge on unconscious priming may have been limited by our use of neutral terms. In Experiment 2 we sought to address this question directly by introducing a systematic difference in word type such that there were both reward salient and neutral terms. All other aspects of the study remain the same as Experiment 1, while the additional manipulation of word type permitted us to contrast the effect of a prior inhibitory task on unconscious priming for reward salient and neutral terms.

Experiment 2

Method

Participants

Participants were 120 volunteers (74 female, 46 male) aged 18 to 41 (*M* = 22.01, *SE* = 0.38) recruited from the University of Sussex and participating in exchange for entry into a £25 prize draw or 2 course credits. Participants were naïve to the experimental hypothesis and were randomly assigned in equal proportions to one of four between subject conditions created by a 2 (inhibitory task: challenge vs. control) x 2 (priming: target word vs. non-word) design. The experiment was considered low risk and received ethical approval from the University of Sussex School of Psychology ethics committee. All participants read an information sheet and signed a consent form before the experiment began. At the end of the experiment participants were fully debriefed as to the nature of the experimental aims.

Materials

All materials were identical to those of Experiment 1 except for the words used in the stem completion task, described here. Two word lists were generated from the British National Corpus online service; 50 reward salient words relating to food and drink, and 50 neutral words, see Appendix A. Reward salient and neutral words were matched for length and frequency of use in written English. As in Experiment 1, no two words began with the same three letters and these three letter stems all had at least two possible alternative completions in the English language.

Design

The experiment exploited a mixed design with three independent variables: Inhibitory task (between subject: challenge vs. control), priming (between subject: word vs. non-word) and word type (within subject: reward salient vs. neutral). The primary dependent variable was the number of stems correctly completed to match the target word. The measure of trait self-control provided by the SCS was included as a covariate.

Procedure

The experimental procedure was the same as in Experiment 1 with the exception that priming was a between-subject condition rather than within-subject, and the primes included two categories of word (reward salient and neutral). This change was made in order to avoid increasing the total number for participants which could otherwise be a confounding factor. As such, participants were either primed with the target words on all 100 trials (word condition) or primed with paired random sequences of consonants (non-words) matched for target word length on all 100 trials (non-word condition). Thresholds for word and non-word stimuli ranged from 35 to 203ms (*M* = 103.69ms, *SE* = 2.79ms), with the complete list of individual thresholds available in the data file provided on the OSF.

Results

Exclusions

Normality checks revealed two extreme outliers; while their removal did not alter the observed pattern of significant effects they were excluded for the analyses reported below.

Inhibitory Control Induced Mental Exhaustion

An independent t-test revealed that participants in the inhibitory challenge condition rated the inhibitory task as significantly more mentally exhausting (*M* = 410.64, *SE* = 15.75) than those in the control condition (*M* = 271.64, *SE* = 21.54), $t(106.21) = 5.21$, $p < .001$, $d = 0.96$.

The Effect of a Prior Inhibitory Challenge on Unconscious Priming

A 2 (inhibitory task: challenge vs. control) x 2 (priming: word vs. non-word) x 2 (word type: reward salient vs. neutral) mixed ANOVA was conducted on the percentage of stem completions that matched the target word (target matches), see Figure 2. The analysis revealed a significant main effect of priming, $F(1, 114) = 5.33$, $p = .023$, $\eta_p^2 = .05$, a significant main effect of word type, $F(1, 114) = 348.03$, $p < .001$, $\eta_p^2 = .75$, no significant main effect of inhibitory task, $F < 1$, and no significant interactions, all $F < 1$.

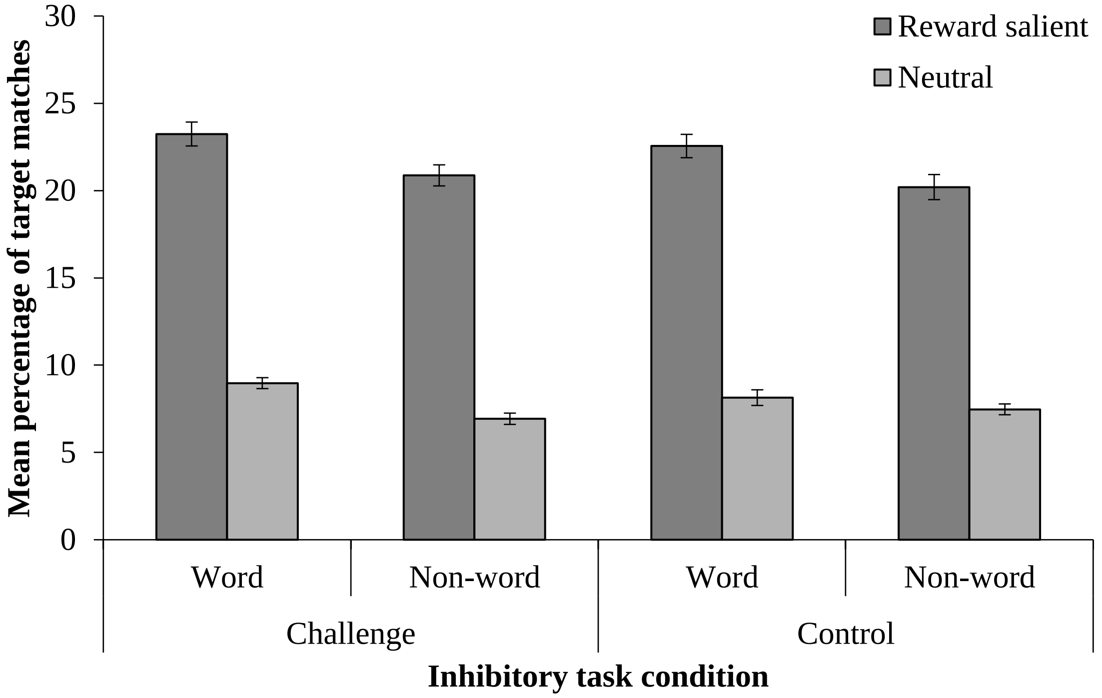

Figure 2. Mean percentage of stem completions that matched the target word by inhibitory task, priming, and word type conditions (+/-1 SEM).

Consistent with Experiment 1, the significant main effect of priming reflected a larger number of target matches for word primes versus non-word primes. The significant main effect of word type indicates that participants were more likely to complete the word stems with reward salient terms than neutral terms. Crucially, again consistent with Experiment 1, the absence of a significant main effect or interaction involving the inhibitory task condition indicates that the inhibitory challenge failed to influence the degree of unconscious priming irrespective of the reward salience of the words. To establish the extent to which the totality of our data provides support for the null hypothesis, namely that a prior inhibitory challenge has no effect on susceptibility to unconscious priming, we combined the two studies in a Bayesian analysis. Specifically, we combined the raw effect sizes of Experiment 1 and 2 weighted by the square of the SE of each estimate and computed a Bayes factor for the combined effect specifying the prior as a uniform distribution from zero to twice the weighted mean of the two control conditions (Weighted *M* = 2.28). This analysis gave a Bayes Factor of 0.23, providing strong evidence for the null hypothesis, that a highly demanding inhibitory task did not increase susceptibility to unconscious priming.

The Effect of Trait Self-Control and Mental Exhaustion on Unconscious Priming

To evaluate the potential effects of trait self-control and mental exhaustion on unconscious priming the above ANOVA was repeated with SCS and reported task-related mental exhaustion included as covariates. This identified a significant main effect of task-related mental exhaustion, $F(1, 112) = 5.06$, $p = .026$, $\eta_p^2 = .04$, and a significant interaction between task-related mental exhaustion and word type, $F\ (1, 112) = 10.55$, $p = .002$, $\eta_p^2 = .09$. No significant main effect of SCS was observed, $F\ (1, 112) = 1.17$, $p = .282$, $\eta_p^2 = .01$, and no significant interaction involving SCS, $F < 1$. Bivariate correlations were used to explore the relationship between task-related mental exhaustion and word type. These revealed a significant positive relationship between task-related mental exhaustion and the percentage of target matches for reward salient words, $r\ (118) = .26$, $p = .004$, and a non-significant negative relationship between task-related mental exhaustion and the percentage of target matches for neutral words, *r* (118) = -.06, *p* = .550, see Figure 3. Note, this effect is independent of priming.

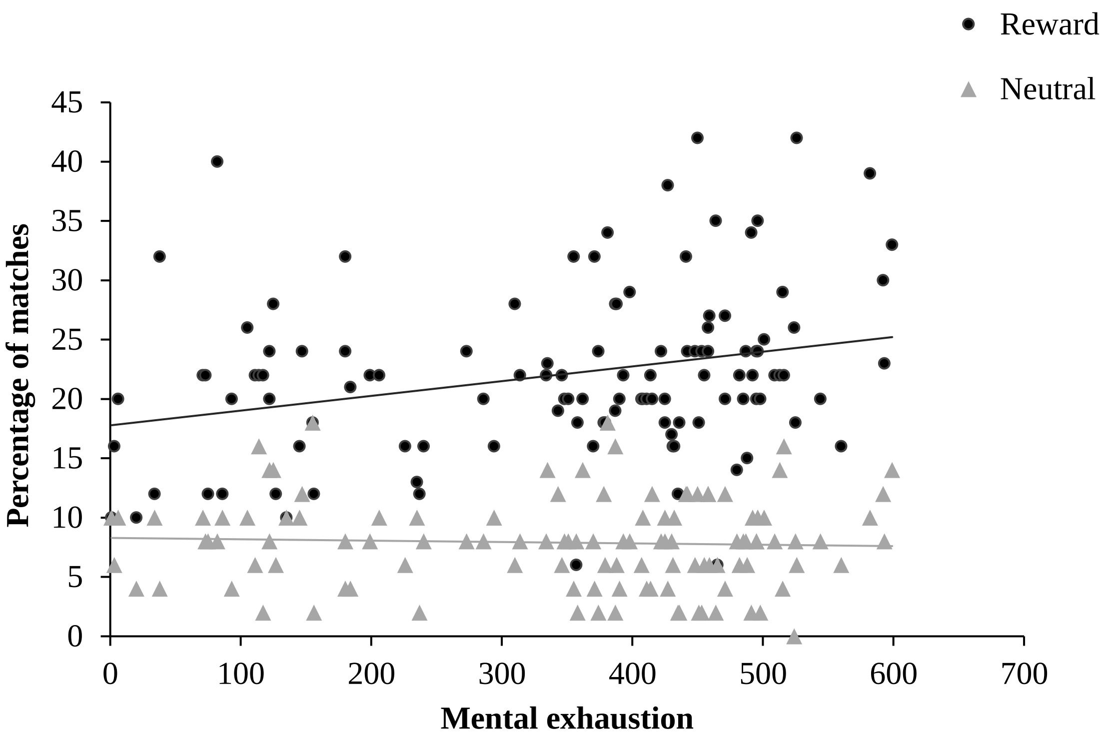

Figure 3. The relationship between reported task-related mental exhaustion and the percentage of stem completions matching reward salient and neutral targets.

Discussion

Experiment 2 sought to establish whether the failure of a prior inhibitory task to influence susceptibility to unconscious priming, as observed in Experiment 1, would hold true where the primes were reward salient rather than neutral. The stem completion task was again found to be sensitive to unconscious priming. The inhibitory task was also again found to be experienced as significantly more mentally exhausting than the control task. Crucially, consistent with Experiment 1, the prior inhibitory challenge was again found not to influence the degree of susceptibility to unconscious priming, regardless of whether the primes were reward salient or neutral terms. Combining the results of Experiment 1 and 2 in a Bayesian analysis provided strong support for the null hypothesis, namely that the prior inhibitory challenge did not influence unconscious priming. Similarly, and again consistent with Experiment 1, neither trait self-control nor task-related mental exhaustion were found to significantly influence unconscious priming.

Interestingly, the results revealed a significant positive correlation between how mentally exhausting participants rated the inhibitory task and the number of stems completed with reward salient targets. While this effect could be considered partially consistent with previous research revealing increased approach behaviour and consumption after highly demanding tasks (Hofmann et al., 2007; Vohs & Heatherton, 2000), it was independent of both the inhibitory task and priming conditions and as such is tangential to the objectives of this study.

General Discussion

Previous research has examined the effect of challenging inhibitory tasks on a range of conscious behavioural outcomes (e.g. Fischer et al., 2012; Vohs & Faber, 2007; Vohs & Heatherton, 2000), but to date none have directly examined the effects on susceptibility to influences elicited unconsciously. Here, we sought to address this by establishing whether the effects observed in conscious contexts extend to unconscious influences. The present study therefore examined the effect of a prior inhibitory task on subsequent susceptibility to unconscious priming. We manipulated the degree to which an inhibitory task was challenging using two versions of a colour classification task, specifically designed to place differing demands on inhibitory processes and examined subsequent susceptibility to subliminal priming using a stem completion paradigm.

Experiment 1 examined the effect of a challenging inhibitory task on subsequent susceptibility to subliminal priming with neutral words in the stem completion task. Experiment 2 extended Experiment 1 by introducing a systematic difference in word type permitting the priming effects to be contrasted between reward salient and neutral terms. The stem completion task proved sensitive to unconscious priming in both experiments, with more primes being used as stem completions. The manipulation of inhibitory demands also proved to be effective in both experiments, with the challenging version of the colour classification task being rated as significantly more mentally exhausting. Crucially however, neither experiment revealed a significant interaction between the degree to which the prior task was taxing and subsequent susceptibility to unconscious priming. Combining the two experiments using Bayesian analysis, provided strong evidence for the null hypothesis that the degree of inhibitory control required by the prior task had no effect on subsequent susceptibility to unconscious influences. The results presented here therefore indicate that completing a task requiring high levels of inhibitory control does not influence an individual's subsequent degree of susceptibility to subliminal priming. Additionally, neither how mentally exhausting individuals rated the colour classification task, nor the measure of trait self-control (SCS) were found to correlate with levels of unconscious priming.

Findings from supraliminal priming research (Bertrams et al., 2015) and the self-control literature in general (see Hagger et al., 2010) appear to demonstrate a reliance on automatic bottom-up processing following a taxing inhibitory task. Had the effects from such research extended to unconscious influences, we would have expected to observe greater levels of subliminal priming for those whose inhibitory processes had previously been burdened by the challenging colour classification task. However, our results suggest that this is not the case and instead that the inhibitory nature of the task does not affect subliminal priming. Unconscious influences appear to be independent of fatigue arising from frontal executive processes.

While our central finding differs to the effects commonly observed in the self-control literature, some interesting parallels can otherwise be drawn. Firstly, in the present study, a significant difference is reported between task conditions, with much higher levels of perceived mental exhaustion being attributed to the challenging versus easy version of the inhibitory task. This is consistent with such inhibitory tasks being used to create a temporary state of mental exhaustion, as has been widely applied in the self-control literature (e.g. Friese, Hofmann, & Wänke, 2008). Secondly, in Experiment 2 those individuals' who rated the colour classification task as more mentally exhausting were found to be significantly more likely to produce reward relevant terms as stem completions. While this correlation does not permit causal conclusions, the observed relationship is consistent with previous research suggesting that where self-control is seemingly reduced individuals exhibit a preference for, and consume more, unhealthy food items (Hofmann et al., 2007; Papies & Hamstra, 2010; Papies et al., 2008; Vohs & Heatherton, 2000).

Given the prevalence of chronically impaired inhibitory control in mood disorders such as anxiety and depression, some reassurance might be taken from our results. The inhibitory challenge common to suffers of such disorders should not, in its own right, result in a greater susceptibility to unconscious influences. However, this can only be concluded within the constraints of the current study which examined only neutral and reward salient primes. Given the established attentional bias towards mood-congruent information in those suffering from depression (Leung, Lee, Yip, Li, & Wong, 2007), stronger conclusions would require our findings to be extended to include stimuli of direct relevance to those mood conditions.

The Bayesian analysis provides certainty that the results represent a sensitive null result rather than reflecting insensitivity. However, future replications might benefit from implementing alternative priming measures with potentially stronger priming effects. Furthermore, while this study rigorously identified participants' subjective threshold of awareness aiming to ensure that the primes were genuinely subliminal, a powerful alternative would be to apply the process dissociation procedure (see Jacoby, 1998). Such a procedure would have the advantage of permitting the direct comparison of controlled (conscious) and automatic (unconscious) influences over the stem completions and would be independent of the absolute threshold achieved.

The current study provides strong evidence that neither an extended period of inhibitory control, nor individuals' level of trait self-control, influences subsequent susceptibility to unconscious influences. This provides further evidence of a difference between unconscious cognitive processes and consciously experienced mental demands. Considering the importance of self-control in shaping human behaviour it is reassuring that prior use of inhibitory processes appears not to leave us open to unconscious influences.

Acknowledgements

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Paper 2:

Hypnotic Suggestibility is Unaffected by a Challenging Inhibitory Task or Mental Exhaustion

Angela Gurney, Wang Hin Wesley Shin, Casandra Petrea, Zoltan Dienes,

Ryan B. Scott

University of Sussex

Author Note:

AG and RS designed the experiments. AG ran the studies with assistance in data collection from two undergraduate students (WS & CP). The analysis and write up were completed by AG with comments and advice provided by RS and ZD.

Abstract

Executive functioning is paramount to the successful exertion of inhibitory control over automatic impulses and desires. Despite disagreements in determining the exact mechanisms responsible for hypnosis, many theories involve the use of, or alterations in, frontal processing and top-down executive functioning. The present study sought to explore this relationship by examining whether a transient state of reduced inhibitory control influences susceptibility to hypnosis. Specifically, participants completed a colour naming task designed to place differing demands on inhibitory control processes before experiencing a hypnotic induction and four suggestions. Bayesian analysis indicated substantial evidence that the prior exertion of inhibitory control processes does not influence subsequent susceptibility to hypnotic suggestion. The study provides evidence that inhibitory impairment, often experienced by those with a range of disorders (such as anxiety and depression), should not affect receptiveness to hypnotic procedures.

Keywords: Self-control; hypnosis; inhibitory control; suggestibility; depletion

Hypnosis refers to two related concepts: A putative altered state of consciousness in which an individual is receptive and attentive to suggestions (Elkins, Barabasz, Council, & Spiegel, 2015); and a way of responding to suggestions involving distortions in the sense of voluntariness and of reality (Kihlstrom, 2008; APA, 2003). Hypnotic response may be facilitated by a hypnotic state, but it need not be: the two concepts are in principle empirically distinguishable (Kirsch, 2011). Hypnosis has been linked to changes in frontal executive functioning (e.g. Egner & Raz, 2007), processes which have previously been reported to be implicated following the application of inhibitory control (see Hagger, Wood, Stiff, & Chatzisarantis, 2010, for a meta-analysis). Furthermore, hypo-frontality has been linked to altered states in general (Dietrich, 2003). This paper will explore whether a transient state of reduced inhibitory functioning influences hypnotic responding.

Hypnotic suggestibility is measured via responses to standard scales of hypnotic susceptibility, such as the Harvard Group Scale of Hypnotic Susceptibility (HGSHS; Shor & Orne, 1962) and the Waterloo Stanford Group Scale of Hypnotic Susceptibility (WSGC; Bowers, 1993), usually involving a hypnotic induction procedure followed by a series of suggestions. Susceptibility varies greatly with around 70-80% of the population being moderately susceptible to suggestion (referred to as ‘medium’ responders), 10-15% responding to few or no suggestions (‘lows’) and the remaining 10-15% responding to most or all suggestions (‘highs’), (Woody, Barnier, & McConkey, 2005). Whilst hypnotic suggestibility is thought to be influenced by modifiable factors such as expectancy (Kirsch & Lynn, 1997), test-retest reliability of an individual’s hypnotic suggestibility has been reported to remain stable over twenty-five to thirty years (Piccione, Hilgard, & Zimbardo, 1989).

Theories of Hypnosis

The best theoretical account of hypnosis remains unresolved. Whilst some suggest that hypnosis stems from an altered state of consciousness (e.g. Bowers, 1992; Hilgard, 1977; Woody & Bowers, 1994), often referred to as 'state-theories', others maintain that hypnosis requires no special state (e.g. Spanos & Coe, 1992; Spanos, 1986).

State theories. Dissociation state models of hypnosis, such as the Neo-dissociation (Hilgard, 1977) and dissociated control (Bowers, 1992; Woody & Bowers, 1994) theories, regard hypnotic responding as based on a state of separation of normal cognitive control systems. The Neo-dissociation theory holds that hypnotic phenomenon come about through a dissociation of high level executive control systems, resulting in distorted motor control, perception, and memory (Hilgard, 1977). Specifically, it is proposed that hypnotic inductions split the central executive functioning into different streams. One stream continues to function normally but due to an amnesic barrier is not consciously accessible, meaning that the hypnotised individual is aware of the resulting action but not of the process eliciting it.

The dissociated control theory (Bowers, 1992; Woody & Bowers, 1994) explains hypnotic responding as a state of dissociation between the supervisory attentional system and the contention scheduling (habit) system. As these systems cease to work together efficiently it results in diminished frontal supervisory attentional control. This dissociation between high level control systems results in a reliance on automatic, low-level, control system processing and thus the feeling of involuntariness which accompanies hypnosis. If hypnosis is due to dissociation, then levels of hypnotic responding should plausibly, positively correlate with dissociative experiences. Research to date has been inconclusive with evidence both of (Kirsch & Council, 1992;

Nadon, Hoyt, Register, & Kihlstrom, 1991) and a lack of (Butler & Bryant, 1997; Dienes et al., 2009) a relationship between everyday dissociative experiences and hypnotic responding.

Non-state theories. Alternative non-state models of hypnosis include Spanos' (1986) socio-cognitive theory which takes the social-psychological perspective that participants' views of hypnosis will affect the degree to which they respond. That is, rather than holding dissociative processes at the forefront of hypnosis, the socio-cognitive approach explains responding in terms of misattributions of experience, and as stemming from strategically responding to demand characteristics and schematic knowledge of what is expected to happen during the hypnotic experience (Spanos & Coe, 1992). For example, a positive hallucination (perceiving something that is not there) could be produced by imagining the stimulus and misattributing the act to hypnosis rather than oneself; a negative hallucination (not perceiving something that is there) could be produced by deliberately ignoring the stimulus without realising one is doing so. Support for the socio-cognitive approach comes from studies reporting that individuals' motivation, expectancy, and beliefs predict their hypnotic suggestibility (Kirsch & Lynn, 1997; Spanos, Brett, Menary, & Cross, 1987). According to Kirsch's (1985) response expectancy version of this theory, the single mediating variable is expectancy, which directly causes the hypnotic response (just as expectancy can directly cause pain relief in the placebo response).

Cold-control theory. The cold control theory (Dienes & Perner, 2007) draws on both the socio-cognitive and dissociation approaches to explain hypnotic responding. According to cold control theory, the distinctive nature of hypnotic responding is entirely metacognitive: A strategic failure to develop a higher order thought (HOT) that one is intending. That is, there is a lack of awareness of the intention to act and consequently, the act is experienced as involuntary. See Norman, Scott, Price, and Dienes (2016), for a demonstration of similar strategic control in the absence of conscious awareness. From this perspective, both Spanos' (1986) non-state and Hilgard's (1977) state theories can be regarded as variants of cold control, because in each case there is an intention to act the subject is not aware of. Conversely, the state dissociated control theory of Woody and Bowers (1994) is not a cold control theory, because hypnotic response is regarded as occurring without executive intentions; and similarly, for Kirsch’s (1985) non-state response expectancy theory: Expectancies, not intentions, cause responses.

The Role of Frontal Function in Hypnosis

Despite disagreements surrounding the mechanisms underlying hypnotic responding, many theories involve the use of, or alterations in, frontal processing and top-down cognitive control. Hilgard’s (1977) and Spanos’ (1986) theories require hypnotic suggestions be carried out by executive functions; thus, disruptions to executive processes should impair hypnotic response. Conversely, the dissociated control theory of Woody and Bowers (1994) likens the hypnotic state to a “functional prefrontal lobotomy” whereby disruptions to executive function should enhance hypnotic response. As Kirsch’s (1985) response expectancy theory holds expectancy as the sole factor underlying hypnotic responding, it would not predict any change in hypnotic response by disruption in frontal function (cf. Buhle, Stevens, Friedman, & Wager, 2012, for independence of placebo effects from distraction). According to the cold control theory of Dienes and Perner (2007), if disruptions to frontal function impair the ability for accurate metacognition, hypnotic response should be facilitated. That is, if it is harder to form accurate higher order thoughts of intending, it will be easier to have inaccurate higher order thoughts when required for hypnosis. However, if frontal function is disrupted without affecting metacognition, then hypnotic response will be unaffected (or impaired, if there is impairment of the capacity to carry out the behavioral or cognitive act required, e.g. imagining, or ignoring a stimulus in the case of positive or negative hallucinations).

There are clinical reasons for postulating a relation between executive function and hypnotic response. Executive functioning is paramount to successful self-regulation, and in exhibiting inhibitory control over automatic impulses and desires. Hypnosis is applied as a valuable tool used to control undesirable behaviours such as in the cessation of smoking (Elkins, Marcus, Bates, Rajab, & Cook, 2006; Green & Lynn, 2000, 2017). Neuroimaging research has provided support for postulating a relation of hypnotic response to frontal function by pinpointing structures involved in top-down regulation (Gazzaley & D'esposito, 2007; Miller & Cohen, 2001) which are consistently implicated in hypnotic responding, such as the frontal and parietal cortices and the anterior cingulate (Cojan et al., 2009; Dienes & Hutton, 2013; Huber, Lui, Duzzi, Pagnoni, & Porro, 2014; McGeown, Mazzoni, Venneri, & Kirsch, 2009). Dienes and Hutton (2013) applied repetitive TMS to the dorsolateral prefrontal cortex (DLPFC), many functions of which such as, logic, willed action, and memory are particularly affected by hypnosis (Dietrich, 2003), and reported that disrupting the DLPFC increased hypnotic responding. Similarly, Semmens-wheeler, Dienes, and Duka (2013) found that alcohol intoxication facilitated hypnotic response.

On the other hand, there is evidence to suggest that cognitive demands created by a secondary task can hamper hypnotic responding (Kirsch, Burgess, & Braffman, 1999). Kirsch et al. (1999) report that cognitive load from an additional task compromised the subjective experience of suggestions such as feelings of rigidity during the rigid arm suggestion. Non-hypnotic tasks appear to interfere with responses to posthypnotic suggestions even when the necessary responses do not conflict (e.g. Tobis & Kihlstrom, 2010). Thus, secondary tasks largely impair hypnotic responding (consistent with Hilgard, 1977, and Spanos, 1986). This may be because hypnotic responding requires executive performance of the required actions, such as control of attention. Nonetheless, the results contrast with the interventions above that facilitate hypnotic response.

In terms of the effect of hypnotic induction on executive function tasks, studies have shown impaired performance (exhibited by longer reaction times) on a colour-naming Stroop task following hypnotic induction, in comparison to non-hypnotised controls (Jamieson & Sheehan, 2004; Sheehan, Donovan, & MacLeod, 1988). Jamieson and Sheehan (2004) suggest that this difference in reaction times demonstrates that it is not the response selection process itself which is altered under hypnotic induction, but rather the efficiency of such processes; thus, there is some evidence that inductions impair executive ability. One explanation for this might be the requirement of executive control processes in order to maintain the altered state itself. However, Jamieson and Sheehan explain such impairments by proposing a modification to dissociative control theory centered around the lDLPFC (left dorsolateral prefrontal cortex). It is suggested that impaired stroop performance during hypnosis is due to a dissociation between the executive control functioning of the lDLPFC and the feedback monitoring processes of the ACC (anterior cingulate cortex) in response to which the lDLPFC would normally implement control.

In terms the relationship between hypnotic response and executive ability, Dienes et al. (2009) found little correlation between hypnotic suggestibility and performance on inhibitory attention tasks; and despite initial promising findings reviewed by Crawford, Brown, and Moon (1993), later Varga, Németh, and Szekely

(2011), and Jamieson and Sheehan (2002), failed to find correlations between various attentional tasks and hypnotisability. Further, Martin, Sackur, and Dienes (2017) showed that one task (perspective switching), previously argued to show differences in attentional abilities between high and low hypnotizable subjects, is sensitive to demand characteristics and motivation differences between high and low hypnotizable subjects. In sum, despite the effects of interventions influencing hypnotic response, individual differences in executive ability seems unrelated to hypnotisability (see Parris, 2017).

One way to reconcile these findings is to postulate that executive resources are needed for the normal behavioural and cognitive acts involved in hypnotic response: Imagination, attentional control, or appropriate action control. These acts do not lose the resources needed for their completion just because they are hypnotic (Dienes & Perner, 2007). Thus, major attention demanding secondary tasks interfere with hypnotic response. Yet special attentional abilities are not needed to perform these everyday acts: hence the lack of correlation of attentional tasks with hypnotisability. On the other hand, if sufficient resources are available to perform the motor or cognitive act, impairing metacognition will enhance hypnotic response (Dienes, 2012). Thus, rTMS to areas shown to be relevant to metacognition, such as the DLPFC (Dienes & Hutton, 2013) and alcohol which prominently affects the DLPFC (Semmens-wheeler et al., 2013) may be especially likely to facilitate hypnotic response. Testing this theoretical resolution requires interventions that impair executive function without harming metacognition.

One potential intervention which meets both of these requirements involves inhibitory tasks commonly employed in the self-control literature. An extensive body of research has previously claimed that applying control on an initial task has a negative impact on an individuals’ subsequent ability to control impulses, urges and behaviours (cf. Dang, 2017; Hagger et al., 2010, with Carter & McCullough, 2014). Such research has reported increased risk taking (Fischer et al., 2012), over-eating (Hofmann et al., 2007; Vohs & Heatherton, 2000), and heightened aggression (DeWall et al., 2007) following a prior task requiring high levels of self-control, such as the colour naming Stroop task. Similarly, Wheeler, Briñol, and Hermann (2007), found that the prior use of inhibitory control decreased subsequent resistance to persuasion. Popular models designed to explain such findings hold that the inability to control behaviours following previous attempts at control stem from either diminishing resources needed to exert self-control (the resource model; Baumeister, Bratslavsky, Muraven, & Tice, 1998), a change in motivation shifting attention away from the need for control and toward rewards (the process model; Muraven & Slessareva, 2003), or from the reallocation of computational mechanisms to a more beneficial task (the opportunity cost model; Kurzban, Duckworth, Kable, & Myers, 2013). The overarching principle of self-control research is that providing the task is mentally exhausting, then subsequent exertion of self-control will be implicated. When the cognitive capacity for control is unavailable, behaviour is instead driven by bottom up processing, impulses, and implicit response tendencies (Bertrams et al., 2015; Hofmann et al., 2007). An issue is ensuring a given task is demanding enough: While one task designed to tax self-control failed to impair subsequent self-control in a large-scale replication (Hagger et al., 2016), a pre-registered study using the Stroop task found subsequent self-control impairments (Dang et al., 2017). The latter study used rated fatigue as an outcome-neutral check on the effectiveness of the Stroop task.

Present Research

The question arises as to what effect taxing inhibitory control would have in hypnotic response; and although it is not the primary focus of the present research to provide support for the various theories of hypnosis it is interesting to consider what these theories would predict. The state dissociated control theory of Woody and Bowers (1994), which compares hypnotic responding to a prefrontal lobotomy, would predict an increase in hypnotic response following a taxing inhibitory task as this disruption to executive function will facilitate hypnosis. Conversely, Hilgard's (1977) and Spanos' (1986) theories require executive functioning to perform hypnotic suggestions. Thus, if inhibitory control tasks temporarily impair executive ability, then Hilgard's and Spanos' theories would predict a decrease in subsequent susceptibility following a taxing inhibitory task. Kirsch's (1985) theory views expectancy as the sole predictor of hypnotic response and thus would predict no effect of inhibitory control tasks on subsequent susceptibility. The predictions of cold control theory (Dienes, 2012; Dienes & Perner, 2007) depend on the effect of inhibitory challenge on metacognition. Gurney, Lagos, Manning, and Scott (2017), showed that the inhibitory challenge used here did not affect subjective thresholds in a subliminal perception task[1]; thus, the formation of accurate higher-order thoughts was not affected. As such, cold control theory predicts that inhibitory challenge would have no effect on hypnotic response unless there is an impairment in the capacity to carry out the cognitive or behavioural act required for the suggestions, in which case responding would be impaired.

Here we tested whether a prior inhibitory challenge would change suggestibility to a set of standard hypnotic suggestions. Specifically, we manipulated inhibitory control processes via the completion of either an easy or difficult version of the colour

[1] Whilst this is not reported in Gurney et al. (2017), the results show substantial evidence of no difference in subjective thresholds between the difficult and easy inhibitory task conditions, (M_{diff} = 6.96, SE_{diff} = 5.56), $t(116) = -1.25$, $p = .213$, $d_z = 0.23$, $B_{N(0, 50.10)} = 0.24$ RR[39.37,100], Note. here the Bayes was modelled as a normal distribution from 0 to halfway between the control mean and the bottom of the scale.

classification Stroop task (cf. Dang et al., 2017). Our outcome neutral test was rated mental exhaustion (cf. Dang et al., 2017). We then examined participants' responsiveness to a hypnotic induction procedure and four standard suggestions including 'magnetic hands', 'rigid arm', and a taste and negative colour illusion. Adopting the stance of the cold control theory, we predicted that hypnotic response would be impaired or remain unaffected for those in the difficult inhibitory control condition.

Experiment 1

Method

Participants

60 participants (45 female, 15 male) aged 18 to 44 years (*M* = 20.70, *SD* = 3.57) were recruited from the University of Sussex Hypnosis Database and paid £5 for participation. Participants had previously been screened using the Waterloo Stanford Group Scale of Hypnotic suggestibility (Form C, Bowers, 1993) and had been rated as 'medium responders' (between 5 to 8 out of 12) for hypnotic suggestibility. Participants were randomly assigned in equal proportions to one of two experimental task type conditions: difficult versus easy inhibitory challenge. All participants were naive to the experimental hypothesis. The experiment was considered low risk and received ethical approval from the University of Sussex School of Psychology ethics committee. All participants read an information sheet and signed a consent form before the experiment began. At the end of the experiment participants were fully debriefed as to the nature of the experimental aims.

Materials

The experiment was implemented in Matlab and run Pavilion DM4 computer with a 15" 60Hz monitor.

A standardised hypnotic induction and four hypnotic suggestions were presented to participants via headphones. The four suggestions included "magnetic hands", "rigid arm", a taste hallucination and a negative colour hallucination. The complete set of materials for both experiments, including the scripts for the hypnotic induction and four suggestions, and the corresponding data has been made publicly available on the Open Science Framework (OSF) and can be retrieved from http://osf.io/xa9p8.

Mood ratings were captured using a Visual Analogue Scale (VAS) for the emotions: happy, sad, anxious, mentally exhausted, aroused and angry, e.g. “At this precise moment how HAPPY do you *feel?”* with ratings provided on a scale from ‘not at all’ (1) to ‘extremely’ (10). These mood ratings were included in order to check that the experimental procedure did not unduly alter any of these five emotions between the experimental conditions prior to the hypnotic induction and thus did not confound the results. Additional VAS were also employed as a measure of self-reported hypnotic experience following each suggestion. Questions for these VAS included "To what extent did your hands move together?", "To what extent did you find it difficult to bend your arm?", and "To what extent did you experience a taste in your mouth?" rated from "Not at all" to "Very much" and lastly, "What proportion of the block pattern did you perceive as being grey?" rated from "None at all" to "The entire pattern".

Two versions of the colour-naming Stroop task, previously shown to be among the stronger manipulations in ego-depletion studies (Hagger et al., 2010), were used as the self-control manipulation, see Procedure section.

The Self-Control Scale (SCS; Tangney, Baumeister, & Boone, 2004), was included as a measure of self-reported trait self-control. The Dissociative Experiences Scale (DES; Bernstein & Putnam, 1986), was included as a self-report measure of dissociative experiences. The Five Facet Mindfulness Questionnaire (FFMQ; Baer, Smith, Hopkins, & Toney, 2006), was used as a self-report measure of five facets of mindfulness including, observing, describing, acting with awareness, non-judging, and non-reactivity. This was included to examine any relationship between mindfulness and hypnotic response. Whilst Lush, Naish, and Dienes (2016) found a negative correlation between mindfulness and hypnotic response; we obtained largely insensitive results, which will be presented, but not discussed further.

Three further questions were included as a debrief in order to ensure that participants were naïve to the experimental hypothesis. These included “What do you think the experiment was trying to test?”, “What do you think was the purpose of the colour classification task?”, and “How do you think being mentally exhausted would affect your hypnotic suggestibility?”.

Design

The experiment adopted a between subjects design with one independent variable: Inhibitory control manipulation (easy vs. difficult). The primary dependent variable was the hypnotic experience ratings taken after each hypnotic suggestion. VAS ratings of mood and mental exhaustion were used as outcome neutral manipulation checks (with changes in mental exhaustion but not mood desired); expectation, and personality measures (SCS, FFMQ, DES) were also captured for correlational analyses.

Procedure

The experiment was conducted in a quiet room with the experimenter available throughout. Instructions were presented on screen and clarification was provided by the experimenter if required. The experiment began with a sound check allowing participants to set a comfortable volume for the audio instructions. Participants then provided demographic information (e.g. age and gender) before instructions for the inhibitory control manipulation were provided.

Inhibitory control manipulation. Participants completed one of two versions of the colour naming Stroop task (easy vs. difficult). Those in the difficult inhibitory challenge condition completed a four-colour version requiring high levels of inhibition of responses to suppress the automatic tendency to read the word in order to report the colour of the text that it is written in (either Red, Green, Blue or Yellow). For example, ‘red’ written in blue must be classified as blue and not red. Participants were asked to be as accurate as possible. Trials began with a 300ms fixation cross before the colour word was presented for 1000ms in ‘Arial’ font size 50. Participants classified the text colour using keys 1-4. Failure to respond within 1 second or to correctly classify the colour resulted in a middle C pitch error tone. There were 240 trials in total with every 8 trials containing 2 trials of each colour word in a randomised order. Each set of 8 trials also contained 6 congruent trials (colour name and text colour match) and 2 incongruent trials (colour name and text colour did not match).

Those in the easy condition completed a two-colour version of the colour classification task, requiring lower levels of inhibitory responses, in which the colour of the text and the word presented were always congruent (i.e. ‘red’ written in red) and were only either red or green. Participants were again asked to keep errors to a minimum. Responses were made using keys 1-2. Each trial began the same way as the four-colour Stroop task but they were asked to classify the text colour as either Red or Green using keys ‘1’ or ‘2’ respectively. The duration of the task was fixed to match the duration of the inhibitory condition, irrespective of the number of trials completed.

Mood ratings. Following the inhibitory manipulation, a set of mood ratings were captured using the on-screen VAS for the emotions: happy, sad, anxious, aroused, angry, and exhausted e.g. “At this precise moment how happy do you feel?” with ratings provided on a scale from ‘not at all’ (0) to ‘extremely’ (10). An additional VAS was used to capture a measure of expectation of participants' level of hypnotic responding.

Hypnotic responding. All participants were instructed to put on their headphones and were asked to listen to the standardised hypnotic induction procedure. This induction was followed by the four separate suggestions in the following order: hands together, rigid arm, taste hallucination, and negative colour hallucination. After each suggestion participants were prompted to give a measure of self-reported hypnotic responding. Responses for the hands together, rigid arm, and taste hallucination suggestions were made using on-screen VAS for the questions; "To what extent did your hands move together?", "To what extent did you find it difficult to bend your arm?" and "To what extent did you experience a taste in your mouth?" respectively, with the scale ranging from "not at all" (0) to "very much" (10). Responses to the negative colour hallucination was measured using a VAS for the question "What proportion of the block pattern did you perceive as being grey?" from "none at all" (0) to "the entire pattern" (10).

Questionnaires. Participants then completed three on-screen questionnaires; the SCS, DES and FFMQ.

Lastly, participants were asked to answer the three on-screen debrief questions before being fully debriefed as to the true nature of the study and thanked for their participation.

Results

All raw data are available at http://osf.io/xa9p8.

Bayes factors (*B*) were used to assess the strength of evidence for the alternative hypothesis, H1, over the null, H0 (Wagenmakers, Verhagen, Ly, Matzke, et al., 2017). A *B* of above 3 indicates substantial evidence for H1 over H0 and below 1/3 substantial evidence for the H0 over Hl. All Bayes factors, *B*, reported here represent the evidence for H1 relative to H0; to find the evidence for H0 relative to H1, take 1/*B*. *B*s between 3 and 1/3 indicate data insensitivity (see Dienes, 2014; cf. Jeffreys, 1939). Here, $B_{H(0,\, x)}$ refers to a Bayes factor in which the predictions of H1 were modeled as a half-normal distribution with an SD of *x* (see Dienes & McLatchie, 2017); the half-normal can be used when a theory makes a directional prediction where *x* scales the size of effect that could be expected. As correlations with hypnotic response, if they exist, tend to be in the region of $r = 0.2$ (e.g. Laurence, Beaulieu-Prévost, & Du Chéné, 2008), for correlations the SD was set to be x = 0.2. For the mood ratings, in the absence of similar previous studies we followed a strategy recommended by Dienes (2017) for this situation. As we predicted that the control group would be happier and more aroused, we estimated a difference between the mean of the experimental condition and the maximum shift possible, thus the SD for mood valence and arousal were set as half the difference between the mean of the difficult condition and the top of the scale (10) (i.e. 3.45/2 = 1.73). For the manipulation check, using the same strategy would result in modeling H1 with a half-normal with SD = 2.65. A previous study (Gurney et al., 2018) using the same difficult and easy tasks and the same measure of mental exhaustion estimated a change of 2.85, virtually the same as the estimate just calculated using the Dienes (2017) strategy. As conclusions do not depend on which SD is used; we chose the more informed value (2.85). Finally, for the change in hypnotic response, theoretically the effect could go in either direction, thus we used a normal distribution to model H1. $B_{N(0,\, x)}$ refers to a Bayes factor in which the predictions of H1 were modelled as a normal distribution with a mean of 0 and an SD of *x* (this can be used for non-directional predictions in general). The maximum difference between the groups is the largest difference between the control mean and the end of the scale. We then set the

SD to be half this maximum. The effect observed in the control condition of Experiment 1 was 4.51 on a 10-point scale, thus, the SD was set to 2.75. With these assumptions for modeling H1, as it happened, where an effect yielded a *p* value of about .05, the Bayes factor was about 3, though there is no guarantee of such a correspondence between *B* and *p* values (Lindley, 1957). We will interpret all effects with respect to the Bayes factors.

To indicate the robustness of Bayesian conclusions, for each *B*, a robustness region is reported, giving the range of scales that qualitatively support the same conclusion (i.e. evidence as insensitive, or as supporting H0, or as supporting H1), notated as: RR [x1, x2] where x1 is the smallest SD that gives the same conclusion and x2 is the largest[2].

Participant Awareness

Responses to the question "What do you think the experiment was trying to test?" which included references to the influence of exhaustion, depletion, will-power (or similar) affecting hypnotic suggestibility were coded as 'aware'. Responses to the question "What do you think the purpose of the colour classification task was?", which mentioned depletion or exhaustion were coded as 'aware'. Finally, any responses to the question "How do you think being mentally exhausted would affect your hypnotic suggestibility?", which stated that it would increase suggestibility were coded as 'increase', those which stated suggestibility would decrease were coded as 'decrease' and 'other' for ambiguous answers. All responses were coded by two independent coders, and codes were found to correspond 100%.

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[2] Thanks to Balazs Aczel for suggesting the use of robustness regions

No participants correctly identified the purpose of the experiment. Out of the five participants who correctly identified the purpose of the stroop task, all thought that mental exhaustion would increase suggestibility.

Correlational Analysis

Expectancy. Pearson's correlation revealed a positive relationship between participants' expectancy ratings and their mean hypnotic response, $r = .28$, $p = .028$, $B_{H(0, 0.20)} = 6.08$, RR[0.09,0.97].

Personality. Correlational analyses were conducted for the relationship between each of the personality measures and mean hypnotic responding, see Table 1. Results show that responses to the DES showed a positive relationship with hypnotic responding.

Table 1. Relationship between mean hypnotic response and all personality measures.

	SCS	FFMQ: Observe	FFMQ: Describe	FFMQ: Act	FFMQ: Non-Judge	FFMQ: Non-React	DES
r	-.13	-.03	-.00	-.12	.00	-.20	.35
p	.310	.838	.995	.348	.981	.132	.006
B	0.31*	0.47	0.55	0.32*	0.55	0.25*	18.63*

Note. * Sensitive *B* at >3 or <1/3.

Outcome Neutral Tests

Exhaustion. There was no evidence one way or the other for there being a difference in mental exhaustion between those in the difficult ($M = 5.49$, $SE = 0.42$) and easy (*M* = 4.69, *SE* = 0.45) conditions, *t*(58) = 1.31, *p* = .197, *d* = 0.34, $B_{H(0, 2.85)}$ = 0.85 RR[0.01, 8.11].

Thus, we have not established, independent of the crucial test, that the tasks challenged the inhibitory system to a different extent. As well as establishing a difference in test difficulty we would also establish that mood was not changed. Changes in mood may accompany different degrees of fatigue as a matter of course, thus establishing no change in mood is not crucial to the logic of the experiment in the same way that establishing differences in inhibitory challenge is.

Mood (valence). There was no evidence one way or the other for there being a difference in valence between those in the difficult (*M* = 3.09, *SE* = 0.61) and easy (*M* = 3.69, *SE* = 0.61) conditions, *t*(58) = 1.31, *p* = .489, *d* = 0.18, $B_{H(0, 3.45)}$ = 0.46 RR[0.01, 4.99].

Mood (arousal). There was no evidence one way or the other for there being a difference in arousal between those in the difficult (*M* = 4.30, *SE* = 0.37) and easy (*M* = 4.67, *SE* = 0.38) conditions, *t*(58) = 0.71, *p* = .478, *d* = 0.18, $B_{H(0, 2.85)}$ = 0.46 RR[0.01, 3.15].

Main Analysis

The effect of a prior inhibitory challenge on hypnotic suggestibility. Here we sought to examine how hypnotic suggestibility differed with inhibitory control condition. A one-way ANOVA was conducted on mean hypnotic response and the inhibitory control manipulation condition (easy vs. difficult). The results revealed evidence for a main effect of inhibitory control condition on subsequent hypnotic response, (M_{diff} = 1.07, SE_{diff} = 0.43), *F*(1, 58) = 6.13, *p* = .016, η_p^2 = .10, $B_{N(0, 2.75)}$ = 3.17 RR[0.39,2.94], with those in the easy rather than difficult condition showing a greater hypnotic response, see Figure 4.

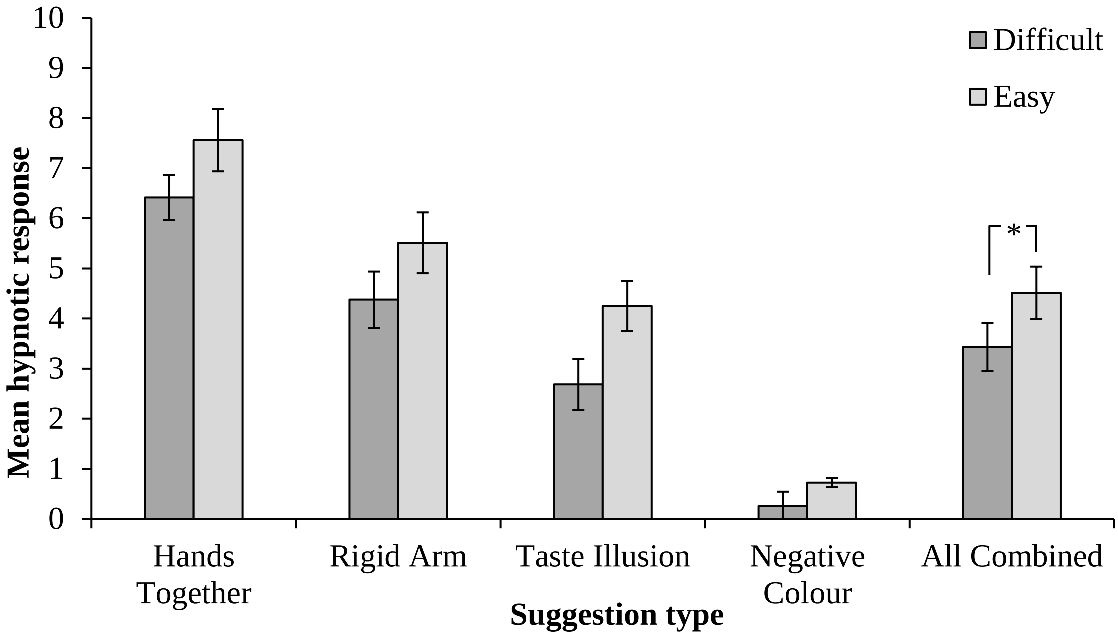

Figure 4. Change in mean hypnotic responding for each hypnotic suggestion as a product of inhibitory condition (+/- 1 SEM). Note. * *p* < .05

Discussion

Experiment 1 aimed to investigate the effect of a prior inhibitory task on subsequent susceptibility to hypnotic suggestions. Consistent with Hilgard (1977) and Spanos (1986) our results suggest that a prior inhibitory task decreases subsequent susceptibility. As such the findings contrast predictions from dissociated control theories of hypnosis which suggest that due to compromised functioning of the frontal cortices there would be an increase in suggestibility to hypnosis. The positive, correlation between participant's dissociative experiences as reported on the DES and their hypnotic responding provides some support for a relationship between dissociative processes and hypnosis. However, one limitation of the inhibitory control literature is ensuring that the task used is mentally exhausting (see Dang, 2017). Whilst the Stroop, as used here, has previously been shown to create necessary inhibitory demand (Dang, 2017; Gurney et al., 2017) we were unable to provide evidence for or against a difference in levels of mental exhaustion for the easy and difficult task conditions. As we did not have clear evidence for this outcome neutral test, and Experiment 1 was run without a pre-defined analytic protocol, we sought to directly replicate the procedure with a larger sample, using the same analyses.

Experiment 2

Method

Participants

96 participants (72 female, 24 male) aged 18 to 45 years (*M* = 20.95, *SE* = 0.41) were 'medium responders' recruited from the University of Sussex Hypnosis Database and paid £5 for participation. Participants were randomly assigned in equal proportions to one of two experimental task type conditions created by the inhibitory control manipulation: easy versus difficult. All participants were naive to the experimental hypothesis. Participants were run until the Bayes factor for the manipulation check indicated substantial evidence for either H1 or H0. The experiment was considered low risk and received ethical approval from the University of Sussex School of Psychology ethics committee. All participants read an information sheet and signed a consent form before the experiment began. At the end of the experiment participants were fully debriefed as to the nature of the experimental aims. The experimental materials, design and procedure all remained the same as Experiment 1.

Results

Participant Awareness

Responses to the three debrief questions were coded as in Experiment 1. No participants simultaneously identified the purpose of the study, the purpose of the stroop and identified that exhaustion would decrease susceptibility. Therefore, all were included in the analysis.

Correlational Analysis

Expectancy. Pearson's correlation revealed a positive relationship between participants' expectancy ratings and their mean hypnotic response, $r = .38$, $p < .001$, $B_{H(0, 0.2)} = 538.22$, RR[0.03, 1].

Personality. Correlational analyses were conducted for the relationship between each of the personality measures and mean hypnotic responding, see Table 2. Results show evidence that responses to the SCS showed a negative relationship with hypnotic responding and the DES showed a positive relationship with hypnotic responding.

Table 2. Relationship between mean suggestibility and all personality measures.

	SCS	FFMQ: Observe	FFMQ: Describe	FFMQ: Act	FFMQ: Non-Judge	FFMQ: Non-React	DES
r	-.21	.01	-.11	-.09	-.14	.02	.33
p	.039	.903	.293	.395	.168	.851	.001
B	5.06*	0.48	0.24*	0.26*	0.21*	0.52	91.04*

Note. * Sensitive *B* at >3 or <1/3.

Outcome Neutral Tests

Exhaustion. There was substantial evidence for a difference in mental exhaustion between those in the difficult ($M = 6.26$, $SE = 0.31$) and easy ($M = 5.07$, $SE = 0.38$) conditions, $t(91.74) = -2.45$, $p = .016$, $d = 0.50$, $B_{H(0, 2.85)} = 5.90$, RR[0.27, 6.06].

This is a key manipulation check to establish the integrity of the experiment. Establishing equivalence of mood would help narrow theoretical interpretation, but as mood may naturally vary with exhaustion (in that, for example, exhaustion is often unpleasant), presence or absence of mood differences do not threaten the integrity of the experiment as such.

Mood (valence). There was no evidence one way or the other for there being a difference in valence between those in the difficult (M = 1.26, SE = 0.57) and easy (M = 2.42, SE = 0.47) conditions, t(94) = 1.56, p = .119, d = 0.32, $B_{H(0, 4.37)}$ = 1.04 RR[0.01, 14.53].

Mood (arousal). There was evidence for the null hypothesis, namely that there was no difference in arousal between those in the difficult (M = 4.44, SE = 0.38) and easy (M = 4.65, SE = 0.31) conditions, t(94) = 0.43, p = .672, d = 0.09, $B_{H(0, 2.78)}$ = 0.24 RR[2.04, 10]. Thus, the differences in mental exhaustion were not accompanied by overall differences in arousal.

Main Analysis

The effect of a prior inhibitory challenge on hypnotic suggestibility. Here we sought to examine how hypnotic suggestibility differed with inhibitory control condition. A one-way ANOVA was conducted on mean hypnotic response and the inhibitory control manipulation (easy vs. difficult). The results revealed substantial evidence for the null hypothesis, namely that there was no main effect of inhibitory control condition on mean hypnotic response, (M_{diff} = -0.17, SE_{diff} = 0.38), F (1, 94) = 0.20, p = .675, η_p^2 = .00, $B_{N(0, 2.75)}$ = 0.15, RR[1.23, 10], see Figure 5.

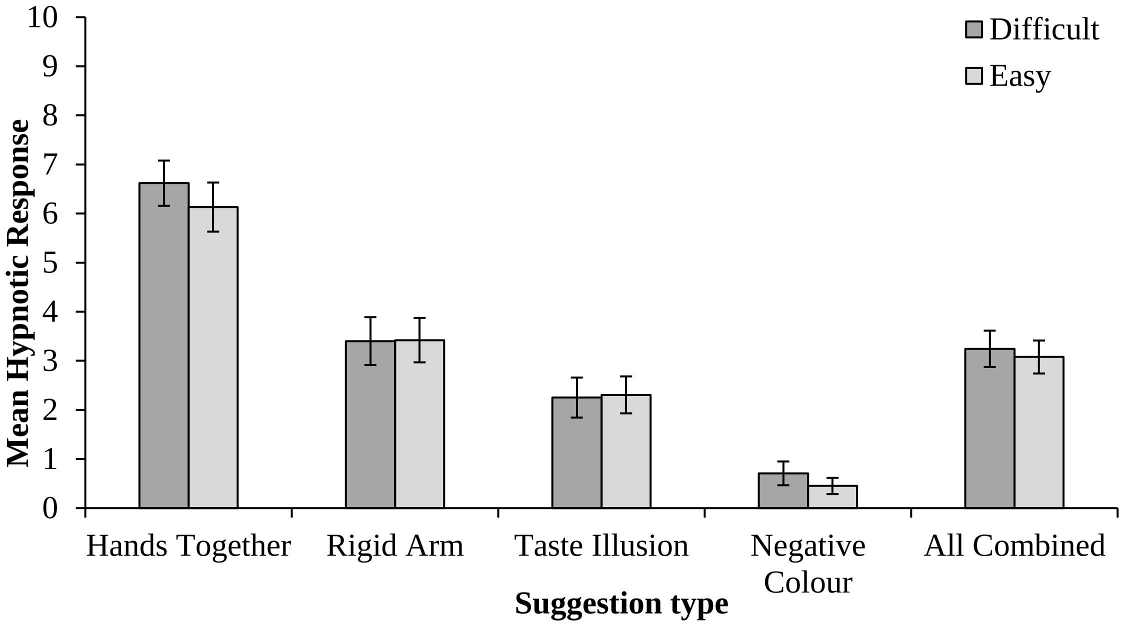

Figure 5. Change in mean hypnotic responding for each hypnotic suggestion as a product of inhibitory condition (+/- 1 SEM).

Next, we tested whether the crucial effect in experiment 1 was different from that in Experiment 2. The results showed substantial evidence for an interaction between condition and experiment, (M_{diff} = 0.81, SE_{diff} = 0.29), F (1, 152) = 4.52, p = .035, η_p^2 = .03, $B_{N(0, 2.75)}$ = 4.63, RR[0.01, 4.38], suggesting that the crucial effect was different in the two experiments. We also tested whether experiment 2 replicated the effect in experiment 1, in the specific sense of using the posterior distribution of the effect found from experiment 1 as the model of H1 for testing the effect in experiment 2 (the strategy recommended by Verhagen & Wagenmakers, 2014). The resulting Bayes provided evidence that Experiment 2 did not replicate the effect observed in Experiment 1, $B_{N(0.80,0.39)}$ = 0.16, RR[1.01, 10]. Finally, we meta-analytically combined the raw effect sizes of Experiment 1 and 2 weighting by the square of the SE of each estimate and computed a Bayes Factor for the combined effect[3]. The resulting Bayes factor provided substantial evidence for the null hypothesis, namely that exerting inhibitory control does not decrease susceptibility to hypnotic suggestion, $B_{N(0, 2.75)} = 0.23$ RR[1.89,10].

Discussion

Experiment 2 sought to establish whether the effect reported in Experiment 1, namely that a prior inhibitory task decreases subsequent susceptibility, would be replicated over a larger sample size. Those in the difficult inhibitory task condition gave higher ratings of mental exhaustion suggesting that the challenging task had the desired effect of increasing inhibitory demand. We found evidence for no effect relative to a relatively uninformed model of H1, and evidence for no effect relative to the effect size found in Experiment 1. Combining both studies in a Bayesian meta-analysis provided support for the null hypothesis that exerting inhibitory processes on a challenging task has no effect on subsequent susceptibility to hypnotic suggestion. As the outcome neutral test was not satisfied in Experiment 1, and the analyses were not pre-defined, we treat Experiment 1 as exploratory (even though the analytic protocol was in fact simple); and Experiment 2 as more clearly testing the theoretical claim that an inhibitory challenge impairs hypnotic response, given the analytic protocol had been pre-defined by that used in Experiment 1.

Consistent with Experiment 1 and previous research there was a positive correlation between scores on the DES in the hypnotic context (Kirsch & Council, 1992; Nadon et al., 1991). This correlation may especially arise when hypnotic

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[3] This is the same as a fixed effects meta-analysis. While the difference between experiments is evidence (but not strong evidence, $B < 10$) that the effect is not fixed, on the null hypothesis we are testing the effect is fixed at zero. That is, if we assume H0, we assume a fixed effect. Note that the same program exactly was run in the same university drawing from the same subject pool (largely psychology undergraduates at the University of Sussex) with no obvious contextual differences that would be relevant according to the theories tested. Thus, it is relevant to test the model there is one fixed effect of zero.

response and DES are tested in the same context (e.g. contrast Dienes et al., 2009, where they were tested in a different context). In addition to this we found a negative relationship between individuals' scores on the SCS and their mean hypnotic responding suggesting that those scoring highest in self-control, reported lower levels of hypnotic responding. Given this result, it is interesting that we did not observe lower levels of hypnotic responding for those who had completed the easy task. This suggests a difference between trait levels of self-control and the level of regulatory capacity altered by inhibitory control tasks. Interestingly, whilst some report a positive relationship between trait self-control and the ability to overcome the effects of 'depletion' (Gillebaart & de Ridder, 2015; Muraven et al., 2005) others have reported the opposite effect (see Imhoff, Schmidt, & Gerstenberg, 2014).

General Discussion

Despite disagreements surrounding the exact mechanisms underlying hypnosis, many theories involve the use of, or alterations in frontal processing and executive functioning (e.g. Dietrich, 2003; Egner & Raz, 2007). As executive functions are vital to inhibitory control, the present study sought to examine whether a temporary reduction in inhibitory control might influence hypnotic suggestibility. We sought to address this by manipulating the degree of demand required to complete a prior task, which consisted of either an easy or difficult colour naming task (see Dang, 2017), and comparing subsequent susceptibility to a set of four standard hypnotic suggestions.

Experiment 1 aimed to investigate the effect of the degree of inhibitory challenge on subsequent hypnotic responding. This constituted an initial exploration. There was not clear evidence for the difference in mental exhaustion produced by the inhibitory tasks in the intervention and control conditions; thus, the required outcome neutral task was not passed. Nonetheless, the results for Experiment 1 provided evidence for the hypothesis that a prior inhibitory task decreases subsequent hypnotic suggestibility. Crucially, Experiment 2, did provide evidence for the outcome neutral task, that is a difference in mental exhaustion between the intervention and control groups, and had researchers' degrees of freedom removed by following the exact protocol as Experiment 1. Experiment 2 found evidence for no effect of prior inhibitory control on hypnotic response. A Bayesian meta-analysis combining the two experiments provided evidence for the null hypothesis that exerting inhibitory processes on a challenging task has no effect on subsequent susceptibility to hypnotic suggestion. The results presented here therefore suggest that the level of demand we placed on inhibitory processes does not influence the degree to which an individual is responsive to subsequent hypnotic influences.

It may be argued that although we had succeeded in placing different levels of inhibitory demand on participants, that difference was not large enough to interfere with hypnotic response. However, the Stroop task used in the experiments in this paper has been pinpointed as one of the strongest and most reliable inhibitory control manipulations in a recent meta-analysis of the depletion literature (Dang, 2017) and has also been used to show subsequently increased stereotype consistent errors (Govorun & Payne, 2006), decreased persistence on puzzle-solving tasks (Webb & Sheeran, 2003, Experiment 1), and reduced performance on tests of handgrip endurance (Bray et al., 2008). Furthermore, it is coupled with a manipulation check in which participants were asked to rate how mentally exhausted they are, a method which is common place within the literature (e.g. Bray et al., 2008; Fischer et al., 2012; Friese, Binder, Luechinger, Boesiger, & Rasch, 2013; Friese, Hofmann, & Wänke, 2008; Friese, Messner, & Schaffner, 2012; Govorun & Payne, 2006; Grillon, Quispe-Escudero, Mathur, & Ernst, 2015; Webb & Sheeran, 2003).

The results presented here are consistent with the cold control theory (Dienes, 2012; Dienes & Perner, 2007) in that previous work disrupting frontal function that improves hypnotic response has been interpreted by cold control as arising from a disruption in metacognition. That is, as cold control predicts an improvement in hypnotic response only where metacognition is affected. Previous research suggests that the inhibitory challenge utilised in the current study (the colour naming Stroop) does not affect the formation of accurate higher-order thoughts (Gurney et al., 2018), thus the cold control theory would predict no alteration - or an impairment in hypnotic responding if the disruption is sufficient to impair the strategies that must be performed to produce the hypnotic action. What cold control theories, including those of Spanos (1986) and Hilgard (1977) rule out is an improvement in hypnotic response by disrupting frontal function.

The results are in themselves consistent with Kirsch's (1985) response expectancy theory, a non-cold control theory, because it regards expectancy as the single direct cause of hypnotic response. The absence of the relevance of disruption of the executive system on hypnotic response is predicted by this theory. However, the results that frontal challenges which impair the formation of accurate higher order thoughts (e.g. Semmens-wheeler et al., 2013) do improve hypnotic response are not predicted by response expectancy theory.

The results do not provide evidence for the original dissociated control theory of hypnosis (e.g. Bowers, 1992; Woody & Bowers, 1994) as such approaches would have predicted an increase in hypnotic suggestibility following a challenging inhibitory task due to an implication of the frontal processes resulting in less control over the further splitting of executive control systems. However, second-order dissociated control models, which locate the dissociation in meta-cognitive monitoring, survive the challenge (Woody & Sadler, 2008). Further, the positive relationship observed between DES scores and mean hypnotic response mirrors findings previously documented (Kirsch & Council, 1992; Nadon et al., 1991) and provides some evidence of a link between dissociative experiences and hypnotic suggestibility, though the absence of this correlation when the measures are taken in different contexts suggests caution in using it to support dissociation theories (Dienes et al., 2009; Kirsch & Council, 1992).

Previous research has shown that exerting control on one task reduces the degree of control which is readily applied to subsequent tasks (e.g. Baumeister et al., 1998; DeWall et al., 2007; Fischer et al., 2012; Hofmann et al., 2007; Vohs & Heatherton, 2000). Thus, if inhibitory control was necessary for hypnosis, the inhibitory control literature would predict impaired hypnotic responding following a task which placed high levels of demand on inhibitory processes. This was not observed in the present study and instead the results show substantial evidence of no effect of prior inhibitory control on hypnotic response. However, interestingly, we do report a negative correlation between individuals' trait levels of self-control and their mean hypnotic responding. This suggests a difference between trait self-control and temporary alterations in regulatory capacity induced by the inhibitory control manipulation. Further, the result suggests that those with low trait self-control should be more receptive to hypnosis. This is important given the clinical applications of hypnosis as a supplementary therapy in populations associated with chronically impaired self-control.

Hypnosis is thought to augment the effectiveness of cognitive behavioural therapies (Kirsch, Montgomery, & Sapirstein, 1995), decrease the symptoms of anxiety and depression (Heap, 2012), and facilitate treatment gains for a variety of psychological and medical conditions (see Green, Laurence, & Lynn, 2014, for a review). Previous work has highlighted the role of chronically impaired inhibitory control in disorders such as anxiety (Cisler & Koster, 2010; Cisler & Olatunji, 2012) and depression (Joormann & Stanton, 2016). Thus, it is interesting and arguably reassuring to report that placing a high level of demand on inhibitory control processes had no effect on hypnotic suggestibility. This encouragingly suggests that, at least within the constraints of study, those with low levels of inhibitory control should be no less receptive to the potentially beneficial effects of hypnosis as a treatment. Further, the correlation between low levels of self-control and high hypnotic response suggests those individuals with disorders characterised by impaired self-control might in fact, be more responsive to the benefits of hypnosis.

Cold control theory (Dienes & Perner, 2007) would predict a change in hypnotic response only where metacognition is impaired. As previous research has shown substantial evidence of no effect of the inhibitory task on subjective thresholds and metacognition (Gurney et al., 2017), cold control theory would predict no change in hypnotic response between inhibitory task conditions as metacognition should remain unaffected. As such, the results presented here provide support for the cold control theory and provide evidence that exerting inhibitory control processes does not influence subsequent susceptibility to hypnotic suggestion. Considering the use of hypnosis in facilitating treatments, it is reassuring that prior inhibitory control demand does not unduly effect receptiveness to hypnotic procedures.

Paper 3:

Mood Lability, Neural Activation, and Resting State Connectivity Following a Demanding Inhibitory Control Task

Angela Gurney, Cassandra Gould Van Praag, Jacob Gough, Amanda Lange, Charlotte Rae, Chris Bird & Ryan B. Scott

University of Sussex

Author Note:

AG and RS designed the two studies. Data collection for Experiment 1 was supported by two undergraduate students (JG and AL). AG completed all data collection for Experiment 2 (fMRI). AG completed analysis for Experiment 1 and completed all preprocessing and analyses for Experiment 2 with support from CGVP and CR. AG completed the write up with comments on the manuscript provided by CGVP, CB and RS.

Abstract

Exerting inhibitory control is understood to result in a reduced capacity for control on subsequent tasks. The present study employed a novel, experimental approach to examine whether performing a task imposing higher versus lower inhibitory control demands increases subsequent susceptibility to mood manipulations. Consistent with predictions, Experiment 1 showed that participants who completed the demanding inhibitory task subsequently showed significantly greater differences in rated happiness and sadness after positive and negative mood manipulations. Experiment 2 then extended this approach by introducing a neuroimaging component to investigate differences in resting state network activation and connectivity, specifically in the default mode and executive control networks, underlying any behavioural changes in mood lability following the prior use of inhibitory control. To this end, participants completed either an easy or difficult inhibitory task flanked either side by a positive mood manipulation and resting-state fMRI scan. The behavioural results revealed no evidence for or against an effect of inhibitory control demand on subsequent mood lability. Significantly increased activation was observed in regions of the default mode network (DMN) and executive control network (ECN) during the second resting-state scan. However, this effect was only observed when the results were collapsed across task conditions. Thus, the results were unable to provide evidence relevant to an effect of prior inhibitory control on cortical activity and resting-state network connectivity.

Keywords: Self-control; emotion; inhibitory control; resting-state

Inhibitory control or self-control, often referred to as ‘willpower’, is a defining feature of the human race and refers to the ability to regulate urges and resist temptation in the pursuit of competing goals. Failure to exert inhibitory control is held to contribute to many of society’s challenges such as the obesity epidemic, debt, drug and alcohol abuse, criminality, and racial discrimination (Inzlicht & Schmeichel, 2012). Despite the importance of inhibitory control in shaping human experience, our current understanding of the mechanisms involved is fundamentally limited and remains a topic of much debate and interest. Thus, the current study aims to investigate the role that self-control plays in one key aspect of our everyday lives: emotion regulation. Whilst much research has documented the link between inhibitory control and emotion regulation, few have experimentally examined the effect of state self-control on subsequent capacity for emotion regulation, and neural connectivity. The present study therefore examines the effect of a demanding inhibitory control task on subsequent mood lability and resting state network connectivity in response to positive and negative mood induction.

Inhibitory control has predominantly been examined using a dual task paradigm to demonstrate that exerting control on one task significantly reduces the amount of control applied to subsequent tasks. In this manner, exerting control on an initial task can lead to subsequently greater levels of undesirable behaviours such as impulsivity (Vohs & Faber, 2007), overeating (Hofmann et al., 2007; Vohs & Heatherton, 2000), aggression (DeWall et al., 2007), and racial stereotyping (Govorun & Payne, 2006), see Hagger, Wood, Stiff, and Chatzisarantis (2010) for a meta-analysis.

One account of such effects, the Resource model (Baumeister et al., 1998), depicts self-control as a resource which once used, needs time to replenish and until such time, cannot be applied to further tasks. However, the resource in question has thus far proven unidentifiable with attempts to characterise it as blood glucose levels (Gailliot et al., 2007; Masicampo & Baumeister, 2008), being subject to much criticism (Beedie & Lane, 2012; Job et al., 2010; Kurzban, 2010; Martijn et al., 2002; Schmeichel & Vohs, 2009; Tice et al., 2007). Whilst further challenges to this model arose from a meta-analysis (Carter et al., 2015) and registered replication report (Hagger et al., 2016) both of which failed to find evidence of the depleting effects of prior inhibitory control, new research has since demonstrated that providing that the task used as the inhibitory control manipulation is experienced as more exhausting, then subsequent effects such as those reported in the self-control literature are apparent (Dang, 2017).

A more recent account of such effects comes from a neural-systems based balance model, by Heatherton and Wagner (2011). The model is built on the concept of a careful balancing act between regions responsible for inhibitory control such as the lateral and ventromedial prefrontal cortex (PFC) and regions involved in processing the valence, appeal, and reward value of stimuli such as the orbitofrontal cortex (OFC) and striatum. Impulse strength is constantly moderated by frontal control, with failures to regulate responses observed where the impulse is stronger than the capacity for regulation or where prior disruption to frontal processes, potentially from prior exertion of inhibitory control, leads to insufficient top-down control (see Wagner, Altman, Boswell, Kelley, & Heatherton, 2013).

Despite the ongoing challenge to encapsulate the underlying foundations of such an effect, a considerable amount of research has collectively reported that exerting control on one task reduces the degree of control applied to subsequent tasks (DeWall et al., 2007; Fischer et al., 2012; Govorun & Payne, 2006; Hofmann et al., 2007; Papies & Hamstra, 2010; Papies, Stroebe, & Aarts, 2008; Park, Glaser, & Knowles, 2008; Vohs & Heatherton, 2000). Although the exact mechanisms underlying the effect remain unknown, it appears that when adequate cognitive capacity is limited, there is a shift from the use of executive top down control to bottom up processes resulting in behaviour being instead directed by impulses, desires and implicit response tendencies (Hofmann et al., 2007).

One facet of cognition requiring inhibitory control is emotion regulation. Emotion regulation refers to the ability to alter the original trajectory of emotion by manipulating one or more of the behavioural, subjective or physiological components of emotional response (Gross & Levenson, 1993). Individuals can change the intensity, duration and quality of emotion either automatically or via the conscious recruitment of strategies such as breathing deeply, biting one's tongue or purposefully thinking happier thoughts (see Gross, 2015). In the absence of successful regulation, emotions can maladaptively bias cognition and behaviour (Eftekhari et al., 2009; Gross & Jazaieri, 2014). Consequently, effective emotion regulation is imperative to healthy adaptation and mental health (Gross & Munoz, 1995).

Emotion regulation and inhibitory control are inextricably entwined; both processes requiring intervention to alter automatic response tendencies. Indeed, tasks involving the inhibition of emotional reactions have been extensively used to experimentally lower levels of self-control (e.g. Baumeister et al., 1998; Friese, Messner, & Schaffner, 2012; Gailliot et al., 2007). While most individuals exhibit an automatic tendency to regulate their emotional responses to affective stimuli (Volokhov & Demaree, 2010), many psychopathologies and disorders characterised by impulsivity are also associated with the failure to regulate emotions (Eftekhari et al., 2009) such as anxiety (Cisler & Koster, 2010; Cisler & Olatunji, 2012), bulimia nervosa (Anestis et al., 2009) and Attention Deficit Hyperactivity Disorder (ADHD; Skirrow et al., 2014; Walcott & Landau, 2004). Thus, better understanding the role of inhibitory control in emotion regulation may help account for observed variations in regulatory capacity seen both in clinical and non-clinical populations (Layton & Muraven, 2014).

Tangney, Baumeister, and Boone (2004), found a positive correlation between high levels of self-control and self-reported emotional stability, suggesting that the two go hand in hand. The self-reports collected in this study however were participants' predictions of how they might respond rather than a rating of their emotions directly after or during emotional experiences. Similarly, Layton and Muraven (2014), looked at two aspects of emotional behaviour: emotional intensity (the degree of positive or negative affect) and emotional lability (fluctuations in positive and negative affect) in two studies. Those high in inhibitory control had greater emotional stability, experiencing lower emotional intensity and fewer fluctuations in mood, suggesting that lower levels of emotional volatility may occur for those high in trait self-control. Consequently, it appears that those who are high in self-control may restrict their emotional experiences by limiting the range of emotion that they exhibit (Layton & Muraven, 2014). Although these correlational designs appear to show a relationship between subjective self-reported mood and trait self-control, experimental designs are required to examine the extent of any causal relationship.

One such experimental investigation exploited neuro-imaging to examine how a demanding inhibitory control task altered subsequent cortical reactivity to emotionally valenced stimuli during an inside-outside judgement task (Wagner & Heatherton, 2013). The study revealed increased left amygdala reactivity to negative stimuli and reduced connectivity between the left amygdala and the ventromedial prefrontal cortex (vmPFC), when viewing emotional images in those who had previously completed a challenging task in comparison to controls. Given that both the amygdala and PFC are known to play an important role in the processing of emotion (Hariri, Mattay, Tessitore, Fera, & Weinberger, 2003) and the importance of the PFC in exerting control over automatic responses (Hare, Camerer, & Rangel, 2009), these results appear to suggest less PFC control over amygdala activation and a period of amplified neural response to negative stimuli following the prior use of inhibitory control. In support of this, a neuroimaging study by Paschke et al. (2016), demonstrated that during emotion regulation individuals high in control exhibited stronger connectivity between the amygdala and PFC, potentially allowing for more effective and better maintained emotion regulation. Considering such findings, we therefore propose that prior exertion of inhibitory control might increase the subsequent intensity and lability of emotional experiences due to a decrease in regulatory capacity.

Task-based functional magnetic resonance imaging (fMRI) paradigms (such as that employed by Wagner et al., 2013), which measure blood oxygen level dependant (BOLD) signal to determine brain regions activated in response to specific stimuli, have been critical to our understanding of how the brain functions (Lee, Smyser, & Shimony, 2013). More recently however, attention has been focused on connectivity in resting state networks (RSNs), as networks identified during resting are understood to be functionally coupled during task-positive states, and resting-state fMRI imaging offers the opportunity to examine multiple networks at one time rather than a single task-associated network (Shen, 2015).

At rest the brain is engaged in spontaneous activity observed as slow fluctuations in BOLD signal (<0.1 Hz) (see Lee et al., 2013). This spontaneous activity shows correlations across brain regions (Fox & Raichle, 2007), which despite being spatially independent appear to be functionally connected (Rosazza & Minati, 2011). One technique used to identify RSNs is independent component analysis (ICA) whereby a number of independent components which show highly correlated patterns of similar

BOLD activity are extracted from the BOLD time series (Mckeown et al., 1998; Rosazza & Minati, 2011). The extracted RSNs, and each of their specific networks of brain areas, show a great deal of consistency across multiple studies and populations and typically include the default mode, executive control, sensorimotor, medial visual, right and left lateralised fronto-parietal, auditory and temporo-parietal networks (see Damoiseaux et al., 2006; Rosazza & Minati, 2011). The same brain regions which show correlated activity during resting-state also exhibit correlated activity during tasks (Shen, 2015); if there is a change within network connectivity it demonstrates that it is comprised of different regions, leading to changes in cognition and behaviour. Therefore, once these RSNs have been identified, alterations in the specific connectivity within the networks may be informative regarding differences observed in behaviour.

The default mode network (DMN), arguably the most studied component, involves the precuneus/posterior cingulate, the lateral parietal cortex and medial prefrontal cortex (Greicius, Krasnow, Reiss, & Menon, 2003; Raichle et al., 2001). The DMN is engaged under 'rest' conditions and deactivated when the individual is performing active tasks, leading to it often being referred to as a 'task-negative' network (Lee et al., 2013). The activity underlying the DMN is thought to reflect self-referential processing, theory of mind, mind-wandering and thinking about past and future events (Buckner, Andrews-Hanna, & Schacter, 2008; Gusnard, Akbudak, Shulman, & Raichle, 2001; Mason et al., 2007) but can be influenced by the characteristics of tasks preceding data acquisition (Rosazza & Minati, 2011). The executive control network (ECN) on the other hand, comprising areas such as the medial frontal gyrus, superior frontal gyrus and anterior cingulate cortex, is referred to as 'task-positive' as it is most intensely engaged during tasks reliant on executive control processes and working memory (Rosazza & Minati, 2011). As such, DMN and ECN activation exhibit instantaneous anti-correlation, such that as task demand increases there is an increase in activation of task-positive regions and a decrease in activation of task-negative regions (see Fox et al., 2005). Both the DMN and ECN are implicated in emotional processing; Whilst regions involved in the ECN such as the anterior cingulate cortex are known to play an important role in monitoring cognitive influences on subsequent emotion (Stevens, Hurley, & Taber, 2011), the DMN has also been shown to play an important role in self-related emotion with apparent differences in DMN connectivity in those with mood disorders such as depression (Greicius et al., 2007; cf. Bluhm et al., 2009). Therefore, it is possible that prior inhibitory control might affect the balanced state between task-positive ECN and task-negative DMN, or connectivity within the networks themselves leading to changes in their subsequent functioning whilst passively listening to highly emotionally valenced music.

The present study employs an experimental approach to directly evaluate the relationship between state inhibitory control and mood lability. Experiment 1 examines whether performing a task imposing high versus low inhibitory control demands increases subsequent susceptibility to a music-based mood manipulation. As an extension of this, Experiment 2 employs a novel design to examine how resting state network connectivity, whilst passively listening to uplifting music, differs with the extent to which a preceding task is mentally demanding. Inhibitory control is manipulated throughout using the e-crossing task which has previously been found to be among the more effective manipulations (Baumeister et al., 1998; Hagger et al., 2010). Emotional state is then evaluated before and after a positive or negative mood manipulation in the form of music. It was predicted that in Experiment 1, participants experiencing the difficult versus easy inhibitory task would subsequently show increased mood lability observed in a greater increase in happiness after positive music and a greater increase in sadness after negative music. The same period of increased mood lability following prior inhibitory control was predicted for Experiment 2. Additionally, it was hypothesised that following increased ECN activity during the difficult inhibitory task, the switch to a restful state would decrease ECN and increase DMN activity during the subsequent mood manipulation; with this change being more pronounced than following the easy inhibitory task. Alternatively, it was also hypothesised that increased ECN activity during the difficult inhibitory task would continue during the mood manipulation, as prior task positive brain states can influence subsequent resting states (Rosazza & Minati, 2011), thus reducing DMN activity. Additionally, changes in mood lability may be accompanied by changes in connectivity within networks, similar to those observed in disorders of emotion regulation such as borderline personality disorder (e.g. Doll, 2013; Wolf et al., 2011). Thus, exploratory analyses are utilised to examine changes in network connectivity during mood manipulation before and after inhibitory control.

Experiment 1

Method

Participants

120 participants (72 female, 48 male) aged 18 to 40 (M = 21, SD = 3.17) were recruited from the University of Sussex and participated in exchange for confectionery and entry into a £25 prize draw. All participants were naïve to the experimental hypothesis and were randomly assigned in equal proportions to one of four experimental conditions created by the two by two design: inhibitory task condition (easy vs. difficult) by mood manipulation condition (positive vs. negative). The experiment was considered low risk and received ethical approval from the University of Sussex School of Psychology ethics committee. All participants read an information

sheet and signed a consent form before the experiment began. At the end of the experiment participants were fully debriefed as to the nature of the experimental aims.

Materials

All instructions, VAS scales, and questionnaires were presented on-screen with the auditory stimuli presented through Dynamode HH-660MV stereo headphones. The controlling program was implemented in MATLAB (Mathworks, 2016) and run on a Pavilion DM4 computer (screen size: 36.5cm x 20.5cm).

The e-crossing task, previously shown to be among the stronger manipulations in self-control studies (Hagger et al., 2010), was used as the inhibitory control manipulation. For this, copies of a page of relatively dense text from a statistical article (Dinno, 2009, p.2) were used (see Appendix D). For the difficult condition, the lightness and contrast of the copies were manipulated to make them more challenging to read, as in Baumeister et al. (1998). Task instructions also differed for the two tasks, see Procedure.

Mood ratings were captured at three times throughout the experiment (see procedure) using a Visual Analogue Scale (VAS) for the emotions: happy, sad, anxious, aroused and angry, e.g. “At this precise moment how HAPPY do you *feel?”* with ratings provided on a scale from ‘not at all’ to ‘extremely’. These mood ratings were included in order to check that the experimental procedure did not unduly alter any of these five emotions between the experimental conditions before the mood manipulation and thus did not confound the results.

An additional VAS was employed as a manipulation check. This captured how mentally exhausting participants found the e-crossing task, with ratings again provided on a scale from ‘not at all’ to ‘extremely’.

The Hospital Anxiety and Depression Scale (HADS, Zigmond & Snaith, 1983), a 14 item, 2 subscale (anxiety and depression) self-report questionnaire was used to measure trait anxiety and depression.

The Barratt Impulsiveness Scale (BIS-11, Patton, Stanford, & Barratt, 1995), a 30 item self-report questionnaire scored on a 4-point ordinal scale (1 = rarely/never, 2 = occasionally, 3 = often, 4 = almost always/ always) was used to measure trait impulsivity. The scale is used to measure multiple impulsivity components and is comprised of 3 second-order factors (attentional impulsivity, motor impulsivity and non-planning) and 6 first-order factors (attention, cognitive instability, motor, perseverance, self-control and cognitive complexity).

The music used for the positive mood manipulation was a two-minute clip of Murzurka from Coppelia by Delibes (1870). The music used for the negative mood manipulation was a two-minute clip of Halloween by Ives (1906). These have previously been validated as effective mood manipulations (Mayer, Allen, & Beauregard, 1995).

Design

The experiment exploited a mixed design with three independent variables: time (within subject: before letter crossing task vs. before mood manipulation vs. after mood manipulation), inhibitory task condition (between subject: easy vs. difficult), and mood manipulation (between subject: positive vs. negative). The primary dependent variable was mood rating measured at each time point. HADS and BIS-11 measures of state anxiety, depression, and trait impulsivity were additionally used as covariates.

Procedure

Participants were given the cover story that the experiment was investigating sustained attention. This was done to avoid revealing the experimental hypothesis whilst providing a reasonable explanation for the tasks involved. Each participant was run individually in a quiet room with the experimenter present throughout. All instructions and tasks were presented onscreen with the exception of the inhibitory control task which was presented in paper form. Participants provided demographic information (age and gender) and completed a sound check to identify a comfortable volume prior to commencing the experiment. The first set of mood ratings were captured using the on-screen VAS.

Inhibitory control manipulation. Participants in the easy condition received two copies of the text. Their instructions were to read through the text and cross out each instance of the letter *'e'*. Participants in the difficult condition completed a harder version of the same task. Their instructions were to cross out each instance of the letter *'e'* unless it was adjacent to, or one letter away from, another vowel. The sheet itself was also visually degraded (lower contrast and blurred) and five copies were provided rather than two. The logic of this task is that the act of inhibiting oneself from crossing out an *'e'* before checking for the additional constraints is more demanding of inhibitory control. The degraded copy is intended to make the task additionally challenging. The provision of five sheets instead of two is intended to imply that the task will take longer; previous research indicates that implying a task will be conducted for longer increases the effect of reduced control (Hagger et al., 2010). Despite the difference in the number of sheets provided, all participants were stopped after 10 minutes; no participant was able to complete two full sheets during this time.

Questionnaires. After the inhibitory control task, participants completed the HADS and BIS-11. The Questionnaires were completed at this stage in the experiment as prior research has indicated that completing additional tasks between inhibitory control manipulations and subsequent control tasks increases the observed effect

(Hagger et al., 2010). Completion of the questionnaires was followed by a second set of mood-ratings identical to the first.

Mood manipulation. Participants were then instructed to put on their headphones, relax and listen to the music; they heard either the positive (Murzurka) or negative (Halloween) clip according to their randomly assigned mood manipulation condition.

After the music stopped, participants completed a third and final set of mood ratings identical to the previous sets. Participants then rated the degree to which they had found the earlier letter crossing task mentally exhausting before being fully debriefed as to the true nature of the study and thanked for their participation.

Results

Inhibitory Control Induced Mental Exhaustion

An independent t-test showed that participants in the difficult inhibitory task condition (M = 60.35, SE = 3.04) rated the e-crossing task as significantly more mentally exhausting than those in the easy condition (M = 43.15, SE = 3.30), $t(117.21) = -3.83$, $p < .001$, $d_z = 0.70$.

The Effect of Prior Inhibitory Control on Mood

Whilst 5 emotions were measured as a set, our analyses focused on happiness and sadness as these were the most relevant to our intended manipulations. In order to ascertain that the e-crossing task itself had no effect on mood two 2 (time: pre vs. post e-crossing task) x 2 (inhibitory control task: easy vs. difficult) mixed ANOVA were performed on ratings of happiness and sadness.

For ratings of happiness there was a significant main effect of time, $F(1, 116) = 4.30$, $p = .040$, $\eta_p^2 = .04$, whereby ratings of happiness before the e-crossing task (M = 65.34, SE = 1.38) were significantly higher than ratings of happiness after the e-crossing task (*M* = 62.79, SE = 1.68), $t(117) = 2.10$, $p = .039$, $d_z = 0.15$. However, importantly there was no significant main effect of inhibitory task condition, $F < 1$, or interaction between time and task condition, F (1, 116) = 1.20, $p = .280$, $\eta_p^2 = .01$.

For ratings of sadness there was no significant main effect of time, task condition, or interaction between time and task condition, (all $F < 1$). Together these results indicate that neither happiness nor sadness differed significantly between the two inhibitory task conditions prior to the music manipulation, and that the e-crossing task used as the inhibitory control manipulation did not itself significantly influence mood. Thus, we proceed to examine how any change in mood induced by the music differs depending on the inhibitory task condition.

Main Analysis

The effect of prior inhibitory control on the modification of rated happiness. Here we sought to examine how changes in rated happiness induced by the two different music mood manipulations (positive vs. negative) differed with inhibitory task condition. A 2 (inhibitory control task: easy vs. difficult) x 2 (mood manipulation condition: positive vs. negative) between subject ANOVA was conducted on change in happiness ratings (ratings after music minus rating before music), see Figure 6. The analysis revealed no significant main effect of inhibitory task condition, $F < 1$. However, there was a significant main effect of mood manipulation, $F(1, 112) = 12.41$, $p = .001$, $\eta_p^2 = .10$, and crucially a significant interaction between inhibitory task and mood manipulation condition, $F(1, 112) = 4.41$, $p = .038$, $\eta_p^2 = .04$.

Given the significant interaction we proceed to evaluate the simple effects of mood manipulation for each level of the inhibitory task condition. In the easy condition no significant difference was found between the change in happiness for those in the positive mood condition (*M* = 3.67, *SE* = 1.26) and those in the negative mood condition (*M* = 0.51, *SE* = 2.10), $t(46.60) = 1.25$, $p = .20$, $d_z = .32$. However, for those in the difficult condition, the change in happiness for those in the positive mood condition (*M* = 8.60, *SE* = 2.69) was significantly different from those in the negative mood condition (*M* = -3.91, *SE* = 2.36), $t(58) = 3.49$, $p = .001$, $d_z = .90$.

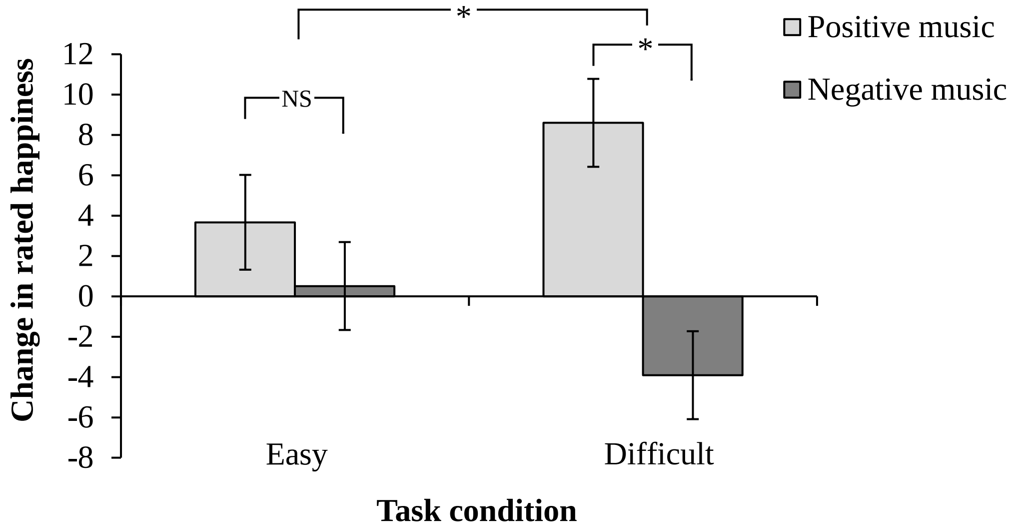

Figure 6. Change in happiness ratings as a product of inhibitory task and mood condition (+/- 1 SEM). Note. * $p < .05$

The effect of prior inhibitory control on the modification of rated sadness. Here we conduct the equivalent analysis examining how changes in rated sadness induced by the two different mood manipulations differed with inhibitory task condition. A 2 (inhibitory control task: easy vs. difficult) x 2 (mood manipulation condition: positive vs. negative) between subject ANOVA was conducted on change in sadness ratings (ratings after music minus rating before music), see Figure 7. Consistent with the observed effects on happiness ratings, there was again no significant main effect of inhibitory task condition, $F < 1$, and a significant main effect of mood condition, $F(1, 116) = 14.76$, $p < .001$, $\eta_p^2 = .11$. However, in this instance the interaction between inhibitory task and mood manipulation condition achieved only marginal significance, $F(1, 116) = 2.83$, $p = .095$, $\eta_p^2 = .02$.

Examining the simple effects of mood for each level of the inhibitory task condition revealed the same pattern of effects as observed for change in happiness. In the easy condition no significant difference was found between the change of sadness ratings for those in the positive music condition ($M = -4.15$, $SE = 1.34$) and those in the negative music condition ($M = 0.13$, $SE = 1.70$), $t(58) = -1.98$, $p = .053$, $d_z = .51$. However, for those who completed the difficult inhibitory task, change in sadness ratings for those in the positive music condition ($M = -5.88$, $SE = 1.76$) were again significantly different from those in the negative music condition ($M = 5.08$, $SE = 2.82$), $t(58) = -3.30$, $p = .002$, $d_z = .85$. Taken together, these results are thus consistent with the hypothesis that prior exertion of inhibitory control increases susceptibility to mood manipulation.

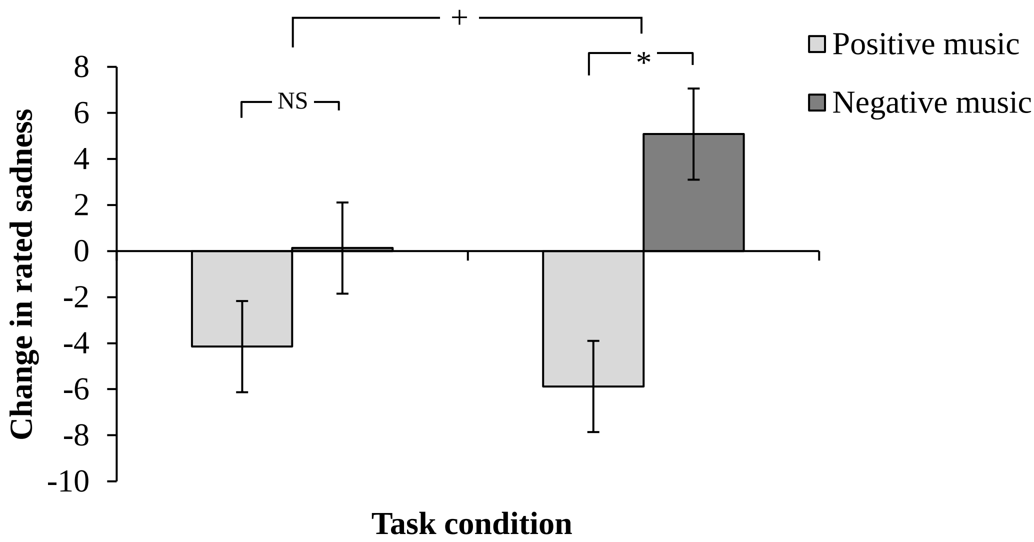

Figure 7. Change in sadness ratings as a product of inhibitory task and mood condition (+/- 1 SEM). Note. * $p < .05$ 2-tailed, + $p < .05$ 1-tailed

Discussion

Experiment 1 aimed to establish whether a prior inhibitory challenge increases mood lability. The difficult inhibitory task was rated as significantly more exhausting than the easy task demonstrating that it appeared to be successful in creating greater inhibitory demand. In line with predictions, participants who completed the difficult versus easy inhibitory task subsequently showed significantly greater differences in mood after positive and negative mood manipulations. These effects were apparent for both rated happiness and sadness. The results indicate that state inhibitory control directly influences the degree to which our mood-state is subject to external influence.

The present experiment supports and extends the existing literature on inhibitory control as the results are consistent with previous findings, namely that prior use of inhibitory processes result in a period in which further attempts to inhibit automatic responses appear to be unsuccessful (e.g. DeWall, Baumeister, Stillman, & Gailliot, 2007; Govorun & Payne, 2006; Hofmann, Rauch, & Gawronski, 2007; Vohs & Faber, 2007; Vohs & Heatherton, 2000). Our results also support studies documenting a correlation between high levels of control and lower emotional intensity and fewer fluctuations in mood (Layton & Muraven, 2014; Tangney et al., 2004). Crucially, the observed period of decreased inhibitory control, and increased mood lability is in line with the documented neurological profile of decreased frontal connectivity and increased amygdala reactivity following a demanding inhibitory task (Wagner & Heatherton, 2013).

In order to examine the neural underpinnings of the effects observed in Experiment 1, Experiment 2 sought to investigate the effect of prior inhibitory control on mood lability using the same paradigm alongside an fMRI component. Here, neural activation and connectivity whilst listening to the positive music mood manipulation is compared before versus after the inhibitory control manipulation. For this reason, participants listen to two pieces of the positive mood manipulation accompanied by a resting state scanning sequence before and after the e-crossing task. It was hypothesised that increased ECN activity during the difficult inhibitory task would result in a rebound effect and increased DMN activity during the subsequent mood manipulation. Alternatively, it was hypothesised that, as prior task positive brain states can influence subsequent resting state (Rosazza & Minati, 2011), increased ECN activity during the difficult inhibitory task would continue during the subsequent mood manipulation, thus reducing DMN activity. Consistent with the results from Experiment 1, it was hypothesised that those completing the difficult versus easy inhibitory task would show a greater increase in change in happiness after the task whilst change in rated happiness before the task should not differ between those in the easy and difficult inhibitory task conditions.

Experiment 2

Method

Participants

Forty-eight, right-handed participants (32 female, 16 male) aged 18 to 35 years (M = 21.98, SD = 4.62) were recruited from the University of Sussex and were paid £15 for participation. The project protocol was approved by the Research Governance and Ethics Committee at the University of Sussex; all participants gave informed consent, were pre-screened for MRI safety with no history of neurological or psychological trauma and were fully debriefed at the end of the study. All participants were naïve to the experimental hypothesis and were randomly assigned in equal proportions to one of two conditions (inhibitory task condition: easy vs. difficult).

Materials

All instructions, VAS scales, and stimuli were presented on screen with the controlling program implemented in MATLAB. Auditory stimuli were presented through scanner safe earphones. Participants made their responses using a four-button button box held throughout in their right hand. Mood ratings and a measure of exhaustion were captured using the same set of VAS used in Experiment 1. Mood ratings were captured at four times during the experimental procedure (see procedure section); as in Experiment 1, these were included in order to ascertain that the experimental manipulation did not unduly affect these five emotions between experimental conditions. Additional VAS were employed as a measure of engagement with the music and distraction during each scanning session. Questions for these VAS included “How engaged were you with the piece of music?”, “During the piece of music, how much did your mind wander?”, and “During the piece of music, how distracted were you by the scanner noise?” rated from “Not at all” to “Extremely”.

The music used for the positive mood induction at both pre and post crossing task scanning sessions were two different 6-minute loops compiled from the same 2-minute clip of Murzurka from Coppelia by Delibes (1870) used in Experiment 1.

The e-crossing task used in Experiment 1, was again employed as the inhibitory control manipulation using the same page taken from (Dinno, 2009, p.2), however here the pages of text were presented on screen. The number of pages, and lightness and contrast of the text were again manipulated in the difficult condition to make the text more challenging to read. Task instructions also differed for the two tasks, see Procedure.

Procedure

Prior to scanning participants provided demographic information (age and gender) and were instructed that they would hear two pieces of music separated by a reading task. Participants were asked to stay as still as possible and to keep their eyes open throughout. The experiment lasted approximately 30 minutes and participants remained in the scanner for the duration. Once settled in the scanner, the experiment began with a sound check to identify a comfortable volume for audio playback. This was followed by the first set of mood VAS before the mood manipulation began.

Mood manipulation and pre-crossing task resting state scan. Participants heard the first piece of music accompanied by the first functional scanning sequence, both lasting for 6 minutes. At the end of the music/scanning sequence, participants completed a second set of mood VAS and a set of the engagement and distraction VAS before being presented with the instructions for the e-crossing task.

Inhibitory control manipulation and structural scan. Participants completed either the easy or difficult version of the e-crossing task. Both of which were accompanied by a structural scanning sequence lasting for 6 minutes. Those in the easy condition were presented with 2 pages of the text and were asked to read through, clicking one button to navigate between pages and a further button every time they came across the letter ‘e’. Those in the difficult condition were presented with 5 pages of the text and were asked to read through pressing one button to navigate through the pages and a further button every time they came across the letter ‘e’ unless it was next to or one letter away from another vowel. Despite the difference in the number of pages provided, the task timed out after 8 minutes and was followed by a 1-minute break accompanied by an on-screen countdown timer. At the end of the 1-minute break participants completed a third set of the mood VAS.

Mood manipulation and (post crossing task resting state scan). Participants then heard the second piece of music accompanied by the second functional scanning sequence again lasting 6 minutes. Participants completed a final set of the mood and engagement/distraction VAS, and the VAS used to measure task related mental exhaustion before being removed from the scanner. Finally, participants were taken to a testing room where they completed a paper version the HADs, were fully debriefed, and thanked for their time. See Figure 8 for a diagram of the procedure for the experimental stages.

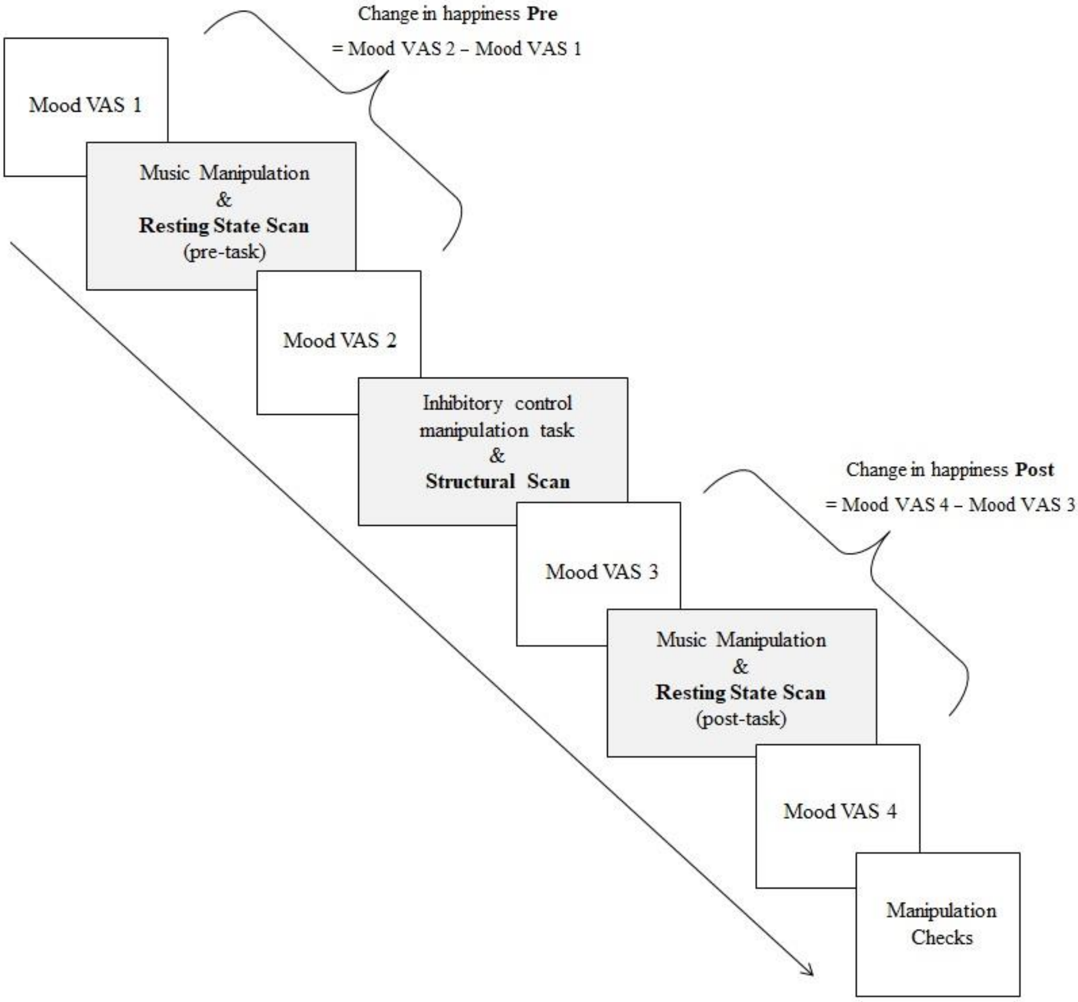

Figure 8. Procedure for Experiment 2 with stages of MRI acquisition shown in grey. Note. The variable 'change in happiness pre' is calculated as happiness levels at mood

VAS 2 minus 1 and ‘change in happiness post’ is calculated as happiness at mood VAS 4 minus 3.

MRI Acquisition

Data were acquired using a 1.5T Siemens Avanto MRI scanner at the Brighton and Sussex Medical School Clinical Imaging Sciences Centre. During the presentation of the two pieces of music, 144 functional volumes were obtained over a period of 6 minutes 17 seconds. These were acquired using a multi-echo Echo-Planar Imaging (EPI) sequence with the following parameters: TR = 2570ms, TE = 15, 34, 54ms, flip angle = 90°, voxel size = 3.8 x 3.8 x 4.2mm, 31 slices, in interleaved, ascending order. T1 weighted MPRAGE structural images were acquired during the inhibitory control e-crossing task using the following parameters: TR = 1160ms, TE = 3.57ms, flip angle 15°, voxel size = 0.9 x 0.9 x 0.9mm. Stimuli presentation was fixed to the acquisition of the 6th volume in order to allow for T1 saturation.

Image Preprocessing

Image preprocessing was completed using Multi-Echo Independent Components Analysis (ME-ICA; Kundu, Inati, Evans, Luh, & Bandettini, 2012), implemented through Analysis of Functional NeuroImages (AFNI) software (Kundu et al., 2013). ME-ICA was invoked at the AFNI command line for each participant using the data from the three echo times (TE = 15, 34, 54ms) and the T1 weighted MPRAGE structural image. The structural image was skull stripped and non-linearly warped to MNI space using the AFNI template (3dQWarp), the functional EPI data were also warped to MNI space and the voxel dimensions were resampled to 5mm isotropic cubes.

ME-ICA uses FastICA to break down the fMRI data into individual components (ICs) based on measurements of Kappa (component scales with TE) and Rho (component does not scale with TE) in order to determine whether or not components are BOLD (high Kappa, low Rho) or Non-BOLD (low Kappa, high Rho) on the basis that true BOLD signal is linearly dependent on TE whilst noise is not. Through the subsequent removal of these non-BOLD, or 'noise' components, ME-ICA is able to denoise the data in terms of motion, physiology and scanner drift, leaving only the BOLD components for further analysis.

Image Analysis

Independent Component Analysis (ICA) was conducted on the de-noised BOLD data using the CONN Functional Connectivity Toolbox (Whitfield-Gabrieli & Nieto-Castanon, 2012). CONN employs Calhoun's group-level ICA (Calhoun, Adali, Pearlson, & Pekar, 2001), with group-level dimensionality reduction to the number of requested components, fastICA to estimate individual components, and back-reconstruction group ICA (GICA1) for subject-level estimation of spatial maps (see Erhardt et al., 2011, for a comparison of ICA approaches). 20 independent components were requested. The resulting components were visually inspected to identify components of interest. 6 Independent Component Networks (ICNs) were identified as commonly occurring networks in healthy controls (Damoiseaux et al., 2006; Rosazza & Minati, 2011). Data was collapsed across time and inhibitory task condition in order to create masks of the DMN and ECN for use in second level general linear model (GLM) analyses of activity within these network areas. ICA maps were also used for between groups exploratory analysis of connectivity differences post inhibitory control manipulation.

First level GLM designs of neural activity were constructed in SPM 8 (Wellcome Trust Centre for Neuroimaging, 2009). Data were modelled as two separate sessions for each participant (pre and post crossing task scanning sessions) and included the 6 motion parameters created during realignment in ME-ICA to remove variance associated with participant motion. First level t-contrasts were created for pre>post, and post>pre comparisons.

A two-factor model was created at second level in SPM 8 with the first level contrasts for pre and post sessions added into the 2 (time: pre vs. post crossing task) x 2 (inhibitory control: easy vs. difficult) design. Second level t-contrasts were created for time: pre>post, post>pre, and inhibitory task: easy>difficult, difficult>easy comparisons.

An initial voxel level uncorrected threshold of $p < .001$ was applied to all second level statistical parametric maps. Clusters surviving False Discovery Rate cluster (FDRc) correction for extent at $p < .05$ were considered significant. Given the a priori hypotheses that differences might be observed in the DMN and ECN, a small volume correction was applied to analyses employing inclusive masks for these networks created at the ICA stage of analysis. Beta-weights were extracted from significant clusters using SPM; The beta weight was extracted as the eigenvariate over the entire cluster. We then conducted t-tests on the extracted eigenvariates of beta weights to confirm the directionality of interactions.

Behavioural Results

Inhibitory Control Induced Mental Exhaustion

An independent t-test showed no significant difference in reported task related mental exhaustion between those in the difficult (*M* = 66.40, *SE* = 4.29) and easy (*M* = 62, *SE* = 4.42) inhibitory task conditions, $t(46) = -0.71$, $p = .479$, $d_z = 0.21$. Bayes analysis was used to determine the strength of evidence for the null hypothesis that there were no differences in rated exhaustion for the easy and difficult task conditions. Using the procedure advocated by Dienes (2014), Experiment 1 estimated a change of

17.2, thus this was used as the SD with a mean of 0 for the prior in a half-normal distribution. In order to indicate the robustness of the Bayesian conclusion, a robustness region is reported and notated as: RR [x1, x2] where x1 is the lowest SD that can be used to give the same conclusion and x2 is the highest. The resulting Bayes, $B_{H(0, 17.20)}$ = 0.63, RR[0.01, 36.60], was between 1/3 and 3 indicating an insensitive result.

The Effect of Prior Inhibitory Control on Mood

Whilst 5 emotions were measured as a set, our analyses focused on happiness as this was the most relevant to our intended manipulation. In order to ascertain that the e-crossing task itself had no effect on mood, a 2 (time: pre vs. post e-crossing task) x 2 (inhibitory control task: easy vs. difficult) mixed ANOVA was conducted on ratings of happiness.

For ratings of happiness there was a significant main effect of time, $F(1, 46) = 17.54$, $p < .001$, $\eta_p^2 = .28$, whereby ratings of happiness before the e-crossing task (M = 61.94, SE = 2.39) were significantly higher than ratings of happiness after the e-crossing task (M = 52.83, SE = 2.36), $t(47) = 4.02$, $p < .001$, $d_z = 0.55$. There was no significant main effect of inhibitory task condition, $F < 1$, however there was a significant interaction between time and task condition, $F(1, 46) = 5.11$, $p = .029$, $\eta_p^2 = .10$.

Given the significant interaction, independent t-tests were conducted to examine the simple effects of inhibitory task condition at each time point. Results showed that before the inhibitory task there were no significant differences in rated happiness for those in the easy (M = 61.17, SE = 3.52) and difficult (M = 62.71, SE = 3.30) conditions, $t(46) = -0.32$, $p = .751$, $d_z = 0.06$. Similarly, after the inhibitory manipulation there were no significant differences in rated happiness for the those in the easy (M = 56.98, SE = 3.80) and difficult (M = 48.69, SE = 2.60) conditions, $t(46) = 1.80$, $p = 0.78$, $d_z = 0.52$.

Examining the simple effects of time for each inhibitory task condition showed that those in the easy condition showed no significant difference in their ratings of happiness before (*M* = 61.17, *SE* = 3.52) versus after (*M* = 56.98, *SE* = 3.80), the e-crossing task, $t(23) = 1.51$, $p = .144$, $d_z = 0.23$. However, those in the difficult condition rated their happiness as significantly higher before (*M* = 62.71, *SE* = 3.30) versus after (*M* = 48.69, *SE* = 2.60) the e-crossing task, $t(23) = 4.18$, $p < .001$, $d_z = 0.96$.

Main Analysis

The effect of inhibitory control on the modification of rated happiness. Here we sought to examine how changes in rated happiness induced by the music differed with inhibitory control manipulation. A 2 (time: pre-cross-out vs. post-cross-out) x 2 (inhibitory control task: difficult vs. easy) mixed ANOVA was conducted on the change in rated happiness (ratings after music minus rating before music at pre and post inhibitory task), see Figure 9.

Results revealed a significant main effect of time, $F(1, 46) = 5.63$, $p = .022$, $\eta_p^2 = .11$, whereby change in happiness was greater post e-crossing task (*M* = 8.27, *SE* = 1.86) in comparison to pre e-crossing task (*M* = 2.75, *SE* = 2.46). However, there was no significant main effect of inhibitory task condition, $F < 1$, and crucially no significant interaction between time and inhibitory task condition, $F < 1$. The resulting Bayes for the interaction, $B_{H(0, 6.54)} = 1.24$, RR[0.01, 36.60], was between 1/3 and 3 indicating an insensitive result.

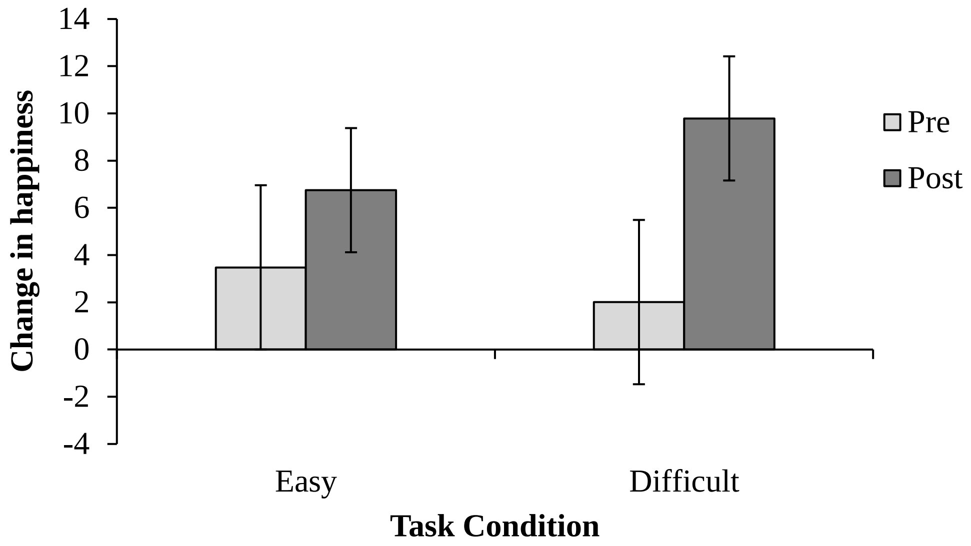

Figure 9. Change in happiness during mood manipulations pre e-crossing task (happiness at mood VAS 2 minus happiness at mood VAS 1) and post e-crossing task (happiness at mood VAS 4 minus happiness at mood VAS 3) by inhibitory task condition (+/-1 SEM).

The effect of personality variables on mood lability. In order to examine any potential covariate effects, the above ANOVA analysis was repeated with the inclusion of each of the following covariates: mental exhaustion, HADS anxiety, HADS depression, music engagement, and scanner distraction. None of the covariates reached significance, all $p > .05$.

fMRI Results

Activation

BOLD activation during resting states was contrasted in a 2 (time: pre vs. post crossing task) x 2 (inhibitory task condition: easy vs. difficult) mixed ANOVA. Given the a priori hypotheses regarding differences in the DMN and ECN and to limit the search to regions involved in these networks, the masks created for each of these during the ICA stage were applied, using a small volume correction and height thresholding at $p < .001$. Results revealed no significant clusters for the main effect of inhibitory task condition, time, nor interaction between time and inhibitory task condition when masking for the DMN and ECN.

The same masks were applied to a planned comparisons t-contrast used to highlight regions showing higher BOLD signal post versus pre-crossing task (i.e. post>pre, collapsed across inhibitory task condition) employing a small volume and FDRc correction with height thresholding at $p < .001$. Results showed two significant clusters in the right superior frontal gyrus and right inferior frontal gyrus pars triangularis (PT) when limiting the search to regions involved in the DMN. Similarly, when limiting the search to regions involved in the ECN, results showed two significant clusters in the right inferior frontal gyrus PT and right middle frontal gyrus, see Table 3. Note that the clusters observed for the DMN and ECN showed considerable overlap. As such, it appears that there were two clusters of activation, each of which spanned over regions involved in both the DMN and ECN, rather than four separate clusters specific to one or the other of the networks, see Figure 10. Graphical representation of the BOLD contrast effect sizes for these clusters can be seen in Appendix E.

Table 3. Significant clusters in regions involved in inclusive DMN and ECN mask, surviving small volume and FDRc correction following height thresholding at p<.001 for the post>pre t-contrast, collapsed across inhibitory task condition. Note ref refers to the label of the relevant cluster shown in Figure 10.

Region	Cluster *pFDR*	*K*	Peak *pFWE*	*Z*	x	y	z	ref
DMN								
R superior frontal gyrus	.010	19	.009	4.48	22	31	45	A
R inferior frontal gyrus (PT)	.035	12	.057	4.08	50	31	17	B
ECN								
R middle frontal gyrus	.027	14	.125	3.91	26	31	45	A
R inferior frontal gyrus (PT)	.027	15	.043	4.16	54	27	17	B

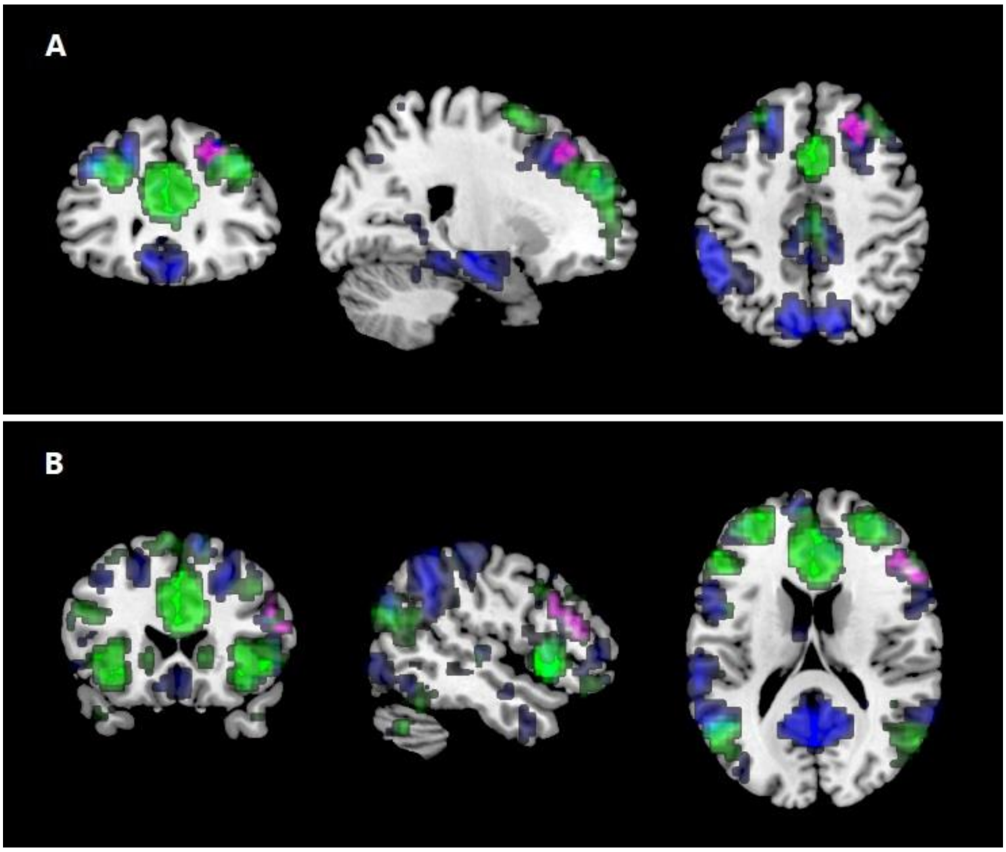

Figure 10. Demonstrating overlap of significant clusters (shown in Violet) for the post>pre t-contrast, surviving small volume and FDR cluster correction following height thresholding at $p < .001$ (as reported in Table 1), when mapped onto masked regions of DMN (blue) and ECN (green). The cluster shown in ‘A’ encompasses the cluster observed in the DMN in the right superior frontal gyrus [22,31,45] (k=19, *p*(FDR cluster)= .010, *Z*=4.48, *p*(FWE peak)=.009), and the cluster observed in the ECN in the right middle frontal gyrus [26,31,45] (k=14, *p*(FDR cluster)= .027, *Z*=3.91, *p*(FWE peak)=.125). Similarly, the cluster shown in ‘B’ encompasses the cluster observed for the DMN in the right inferior frontal gyrus PT at [50,31,17] (k=12, *p*(FDR cluster)= .035, *Z*=4.08, *p*(FWE peak)=.057), and that observed for the ECN in the right inferior frontal gyrus PT at [54,27,17] (k=15, *p*(FDR cluster) = .027, *Z*=4.16, *p*(FWE peak)=.043).

Exploratory, whole brain analyses were additionally conducted to identify effects outside of the hypothesised RSNs. No significant main effect of time, task condition, nor interaction between the two was observed. However, a planned comparisons t-contrast for post>pre revealed significant clusters surviving FDRc correction following height thresholding at $p < .001$ in the right angular gyrus, left inferior occipital gyrus and left middle frontal gyrus (see Table 4 and Figure 11). Graphical representation of the BOLD contrast effect sizes for each of these clusters can be seen in Appendix F.

Table 4. FDR corrected clusters following height thresholding at $p < .001$ for the whole brain post>pre t-contrast, collapsed across inhibitory task condition for regions not involved in the DMN and ECN masks.

Region	Cluster *pFDR*	*K*	Peak *pFWE*	*Z*	x	y	z
R Angular Gyrus	.005	21	.146	4.20	42	-57	49
L Middle Frontal Gyrus	.006	19	.626	3.86	-42	15	41
L Inferior Occipital Gyrus	.041	11	.713	3.79	-42	-69	-3

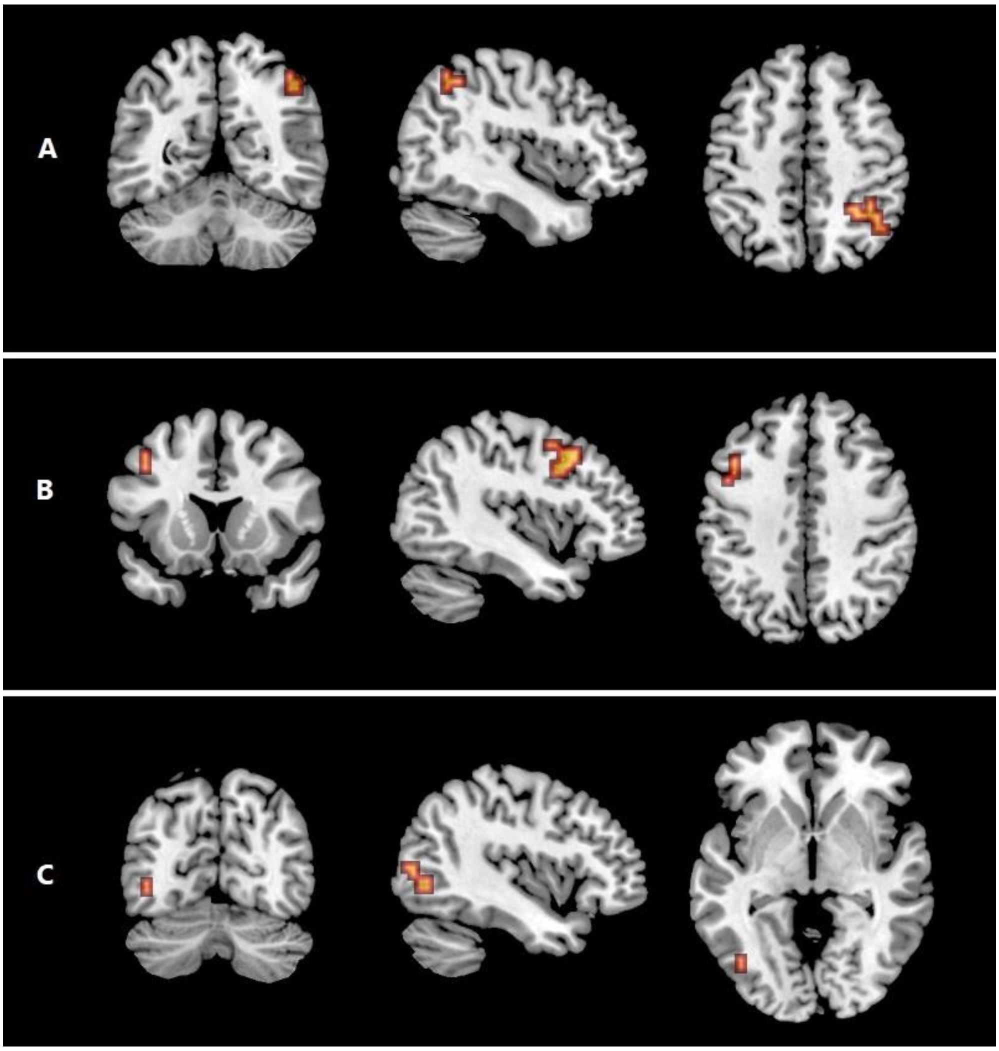

Figure 11. Significant clusters for the post>pre t-contrast, surviving FDR cluster correction following height thresholding at $p < .001$ for regions outside of the DMN and ECN masks in: (A) right Angular Gyrus [42,-57,49] (k=21, *p*(FDR cluster)= .005, *Z*=4.20, *p*(FWE peak)=.146); (B) left Middle Frontal Gyrus [-42,15,41] (k=19, *p*(FDR cluster)= .006, *Z*=3.86, *p*(FWE peak)=.626); (C) left Inferior Occipital Gyrus [-42,-69,-3] (k=11, *p*(FDR cluster)= .041, *Z*=3.79, *p*(FWE peak)=.713). Colour scale (black – red – white) represents t-score range from 0 to 1.5.

In order to identify regions in which activation observed in the post>pre contrast was correlated with the observed behavioural effects, second level one sample t-tests were constructed, using the first level post>pre t-contrast for each participant, with each of the following behavioural measures added as covariates: task related mental exhaustion, change in happiness at post minus pre, and HADS anxiety and depression subscales. BOLD signal did not correlate with any of the behavioural covariates and the inclusion of each of the covariates had no effect on the pattern of results observed in the post>pre contrast.

In the absence of a main effect of inhibitory task condition or interaction between time and task condition, a planned t-contrast was used to highlight regions exhibiting higher BOLD signal for the difficult versus easy crossing task condition (i.e. Difficult>Easy, collapsed across time). Results revealed no clusters or peaks surviving FDR cluster correction following height thresholding at $p < .001$. A full table of significant clusters for t-contrasts for each level of group and condition (i.e. pre, post, easy, difficult) can be found in Appendix G. Crucially the lack of significant clusters for the main effect of inhibitory control task or interaction between time and inhibitory task, suggests no effect of prior inhibitory control on subsequent activity within the DMN or ECN.

Connectivity

The 6 components identified in the ICA stage as commonly occurring networks in healthy controls can be seen in Figure 12. Second level analysis was conducted using the RSN maps identified as the DMN and the ECN at each time point. A 2 (time: pre vs. post crossing task) x 2 (inhibitory task condition: easy vs. difficult) ANOVA showed no effects of group or condition on connectivity (all clusters p >.05 FDR, all peaks p >.05 FWE). The behavioural exhaustion, engagement, and distraction measures, scores on the HADS and change in happiness were added as covariates into the analyses; there were no significant clusters (at FDR p >.05) or peaks (at FWE p >.05) relating to any of these covariates, indicating that there were no regions within these networks in which connectivity was correlated with the behavioural covariate. Crucially, the lack of significant clusters for the main effect of time and inhibitory control or interaction between the two suggests no effect of prior inhibitory control on subsequent connectivity within the DMN or ECN.

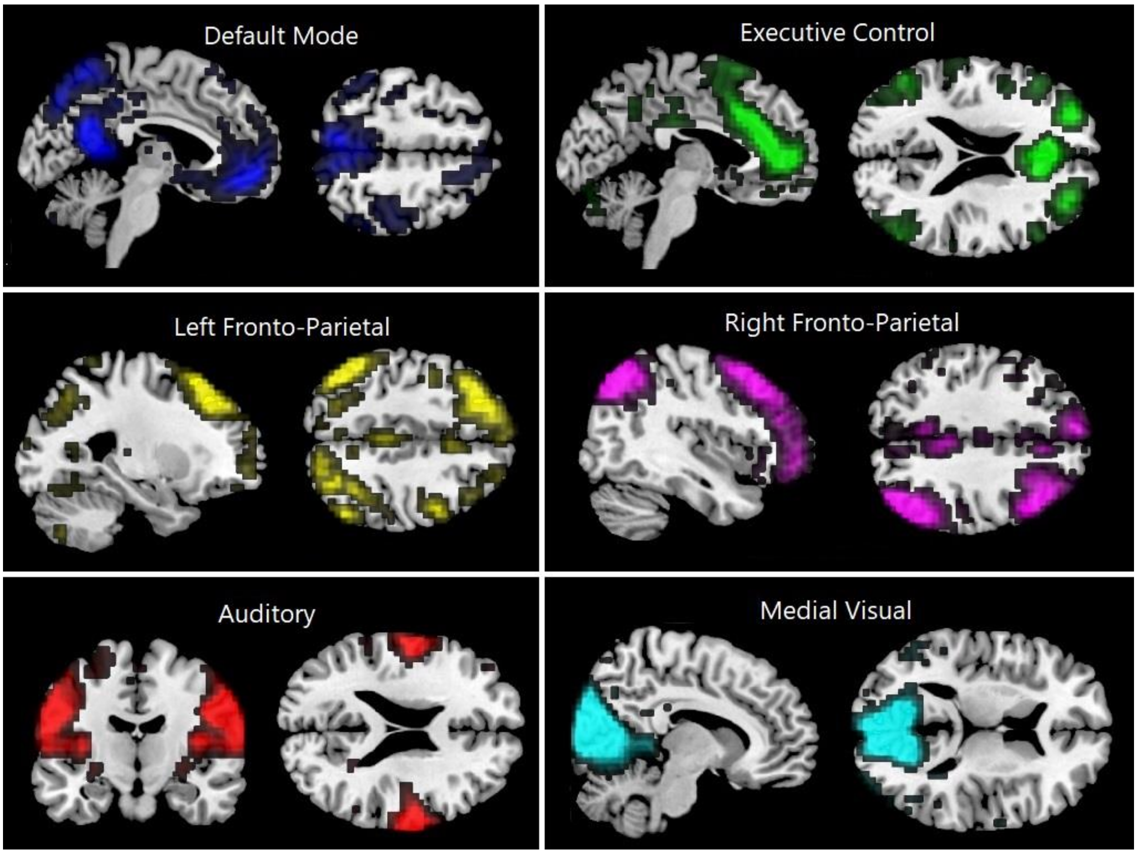

Figure 12. Resting state ICNs, collapsed across crossing task condition. The ICNs reported here are consistent with those previously identified in control populations (Damoiseaux et al., 2006). Threshold uncorrected peak p<.001.

Discussion

Experiment 2 investigated the neural underpinnings of the period of increased mood lability following prior inhibitory control observed in Experiment 1. In contrast to Experiment 1 and previous research (see Dang, 2017) the behavioural results revealed no difference in ratings of task exhaustion between those in the easy and difficult inhibitory task conditions and Bayesian analysis indicated data insensitivity.

Again, in comparison to Experiment 1, here the results revealed a significant main effect of time whereby there was a greater change in happiness the second-time participants heard the music (immediately after the e-crossing task). However, there was no main effect of inhibitory task condition nor interaction between time (music manipulation pre vs. post e-crossing) and inhibitory task condition.

Using ICA of the BOLD response at rest whilst participants were listening to the music both before and after the inhibitory control manipulation, we successfully identified six RSNs documented elsewhere (e.g. Damoiseaux et al., 2006; Rosazza & Minati, 2011). We found no evidence of significant main effect of time, inhibitory task condition, or interaction between the two on differences in BOLD activation within the DMN. Planned comparisons (post>pre), utilised to highlight regions of higher BOLD signal post versus pre inhibitory control manipulation within regions involved in the DMN, revealed significant clusters of activation in the right superior and inferior frontal gyrus. Similarly, no significant main effect of time or inhibitory task condition was observed for BOLD activation within the ECN. However, planned comparisons (post>pre) revealed significant clusters of activation in the right inferior and middle frontal gyrus. Additional exploratory whole brain analyses revealed significant clusters showing greater activation post versus pre (post>pre) inhibitory control manipulation in the right angular gyrus, left inferior occipital gyrus and left middle frontal gyrus. Furthermore, we found no evidence of a significant effect of time or inhibitory task condition on differences in connectivity within the networks of interest (DMN and ECN), nor in exploratory analysis of the auditory, medial visual and bilateral fronto-parietal networks, suggesting no effect of prior inhibitory control on subsequent connectivity within RSNs. Crucially, whilst these results show no significant evidence of an effect of prior inhibitory control on subsequent activity or connectivity within the hypothesised networks (DMN and ECN), the results highlight regions of DMN and ECN exhibiting heightened activation at post versus pre inhibitory task.

General Discussion

Previous research has documented the close relationship between inhibitory control and emotion regulation (Layton & Muraven, 2014; Pashke et al., 2016; Tangney et al., 2004; Wagner & Heatherton, 2013) but to date none have directly examined the effect of prior inhibitory control on changes in resting state network activity or connectivity underlying increased emotional lability. Thus, the present study investigated the effect of prior inhibitory control on subsequent mood lability experienced in response to music-based mood manipulations. The degree of inhibitory control was manipulated throughout using two versions of the e-crossing task designed to place differing levels of demand on inhibitory processes.

Experiment 1 examined the extent of prior inhibitory demand on subsequent mood lability. Experiment 2 then extended this approach by introducing a neuroimaging component to investigate differences in resting state network activity and connectivity underlying any behavioural changes in mood lability following the prior use of inhibitory control. Consistent with previous research (e.g. Hagger, Wood, Stiff, & Chatzisarantis, 2010) the manipulation of inhibitory demand proved to be effective in Experiment 1 with the difficult version of the e-crossing task being rated as significantly more exhausting than the easy version. Experiment 2 did not elicit the same between condition difference in levels of mental exhaustion, and Bayesian analysis provided evidence of data insensitivity. It is important to note that this indicates that the inhibitory control manipulation employed for the purposes of Experiment 2 did not prove to be effective, a point which is discussed further below.

The results of the main analysis in Experiment 1 revealed greater differences in emotional lability to positive and negative mood manipulations for those previously experiencing a demanding inhibitory control task. The results therefore supported previous studies which have reported lower levels of emotional lability for individuals high in inhibitory control (Layton & Muraven, 2014; Tangney et al., 2004). The findings were also consistent with the existing literature which appears to demonstrate that the prior use of inhibitory control results in a period in which further attempts to exert control are often met with failure (e.g. DeWall, Baumeister, Stillman, & Gailliot, 2007; Govorun & Payne, 2006; Hofmann, Rauch, & Gawronski, 2007; Vohs & Faber, 2007; Vohs & Heatherton, 2000). However, the behavioural results from Experiment 2 showed no main effect of inhibitory control task on subsequent differences in emotional lability, and the resulting Bayes factor indicated data insensitivity.

The fMRI results showed no evidence of a significant effect of inhibitory task condition on subsequent activation within either of the hypothesised networks (DMN and ECN). However, when collapsed across task condition the results revealed clusters showing significantly higher BOLD signal after, in comparison to before, the inhibitory control manipulation in clusters overlapping regions of both the DMN and ECN. These clusters of activation were in the right superior frontal gyrus, right inferior frontal gyrus PT and right middle frontal gyrus. Two hypotheses regarding the DMN and ECN were originally made. The first hypothesised that due to an increase in task-positive (ECN) network activity during the difficult inhibitory task, we would observe a switch to increased DMN and decreased ECN activity during the restful conditions of the subsequent mood manipulation. Alternatively, the second hypothesis was based on previous research showing that prior task positive brain states can influence subsequent resting state (Rosazza & Minati, 2011) and thus predicted that increased ECN activity during the difficult inhibitory task would continue during the subsequent mood manipulation, thus decreasing DMN activity. Interestingly, the results show evidence of periods of both increased ECN and increased DMN activity during the second mood manipulation, supporting both of these hypotheses to a degree. However, as these clusters show a large amount of overlap it is not possible to meaningfully interpret this result in terms of activation of either of the networks. Furthermore, these effects were only observed when task condition was not taken into consideration. In addition, the results revealed no significant effects of time nor inhibitory task condition on changes in RSN connectivity. Thus, we were unable to replicate the decreased frontal connectivity following prior inhibitory control previously observed by Wagner and Heatherton (2013).

As previously discussed, the inhibitory control manipulation employed in Experiment 2 failed to create a significant between-groups difference in rated mental exhaustion. One limitation of the inhibitory control literature is ensuring that the task employed is demanding enough. Previous research shows that providing a task is experienced as exhausting, it is likely to show 'depleting' consequences on subsequent behaviour and cognition (Dang, 2017). It is therefore interesting to consider whether the on-screen manipulation used for the purposes of Experiment 2 met that requirement. Certainly, we believe this is one of the first on-screen applications of the e-crossing task using this format. vanDellen, Shea, Davisson, Koval, and Fitzsimons (2014), previously administered an online version of the e-crossing task where participants were presented with a page of text and were asked to retype it omitting the letter 'e' according to specific rules. The e-crossing task was used in the current study to most closely replicate Experiment 1, however it is interesting to consider whether the on-screen version is inherently exhausting. The average ratings of task related mental exhaustion for the easy and difficult conditions in Experiment 1 were approximately 43 and 60 out of 100 respectively. In contrast, in Experiment 2, both the easy and difficult conditions were rated above 60 suggesting that the easy task was experienced as comparatively exhausting when conducted in a brain imaging scanner. For this reason, future investigations should consider evaluating different inhibitory tasks with the goal of identifying those which most effectively translate into the scanner environment.

The results from Experiment 1 indicate that prior inhibitory control plays a role in the subsequent regulation of emotion. It appears that a temporary period of reduced capacity for control results in increased mood lability where external stimuli more easily influence individuals. However, limitations in the inhibitory control manipulation when applied in the fMRI context in Experiment 2 meant that the study is unable to provide evidence relating to whether these effects are supported by changes in neural activation or resting-state connectivity.

Paper 4:

Affective Evaluations are Uninfluenced by the Manipulation of Inhibitory Control and Mindfulness

Angela Gurney and Ryan B. Scott

University of Sussex

Author Note:

AG designed the experiments and collected the data with support from four undergraduate students (SF, CM, CB, & CW). AG performed all analyses and the write up with comments and advice from RS.

Abstract

There is an established relationship between chronic weakness of inhibitory control and the likelihood of disordered mood. In contrast, sustained mindfulness practice has been associated with improvements in emotion regulation. Here we investigate whether a short-term inhibitory challenge increases our emotional response to stimuli and whether a brief mindfulness exercise has the effect of moderating such affective responses. Participants rated positive and negatively valenced pictures after one of two types of manipulation. In Experiment 1, picture ratings were contrasted for participants completing either an easy or challenging inhibitory task. In Experiment 2, ratings of the same images were contrasted for participants completing either a mind-wandering or mindfulness manipulation. Manipulation checks confirmed the difficult inhibitory task to be significantly more exhausting than the easy task (Experiment 1) and that there was no significant difference in engagement between the mind-wandering and mindfulness tasks (Experiment 2). Bayesian analysis provided strong evidence that participants' valence ratings were unaffected by either a prior inhibitory task or mindfulness manipulation. While here we examine valence ratings and not direct measures of mood, the results suggest that the short-term depletion of inhibitory resources does not result in an increase in emotional response typically observed in chronic conditions. Similarly, a brief mindfulness manipulation does not produce the moderating effects on emotional experience found to result from extended practice.

Keywords: Emotion regulation; mindfulness; inhibitory control; self-control; mood

Emotion plays a vital role in shaping how individuals interact with the ever-changing environments surrounding them. The ability to adapt and influence one's own emotions in order to ensure that they are helpful rather than harmful is referred to as emotional regulation (Gross, 2015), a capacity which is inextricably linked to the ability to exert inhibitory control over automatic responses. One technique thought to contribute to successful inhibitory control and the effective regulation of emotion is mindfulness; a meditative practice which has undeniably gained considerable attention over the last few decades (Teper, Segal, & Inzlicht, 2013). Evaluating the extent to which emotional lability is affected by the prior use of inhibitory control could extend our understanding of how emotional trajectories are exacerbated by extraneous factors which drain cognitive resources. In turn, understanding whether mindfulness meditation is successful in reducing the variability in emotion lability, offers additional support to the established literature which highlights mindfulness as a useful and efficient technique employed in balancing emotions (see Chambers, Gullone, & Allen, 2009). Thus, with inhibitory control being paramount to healthy and effective emotion regulation and mindfulness training potentially facilitating such processes, it is important to better understand how emotion regulation is affected by each of these components in turn. The present study therefore examines the effect of a prior inhibitory task, and a mindfulness meditation procedure, on subsequent emotion lability captured via the perception of emotionally relevant stimuli.

Effective emotion regulation is the successful manipulation of the intensity, duration, and quality of the emotional response (see Gross, 2015). Such changes to the emotional response can happen automatically or through the conscious application of regulatory strategies such as biting one's tongue or breathing deeply. Emotions can maladaptively bias cognition and behaviour (Eftekhari et al., 2009; Gross & Jazaieri,

2014) meaning that effective emotion regulation is an essential component to mental health (Gross & Munoz, 1995). For example, emotion regulation, in terms of understanding one's strategies and their ability to modify their emotions, is held as paramount to the understanding of the onset, maintenance, and necessary treatment of anxiety related disorders (Cisler & Olatunji, 2012; Cisler, Olatunji, Feldner, & Forsyth, 2010).

One capacity responsible for individual differences in emotion regulation is inhibitory control (Paschke et al., 2016). In fact, inhibitory control and self-reported emotional stability are highly correlated (Tangney et al., 2004). Individuals high in control, experience fewer fluctuations in mood and lower intensities of emotion (Layton & Muraven, 2014). It is interesting to question whether this is due to an individual's ability to restrict their emotional experiences. Whilst the necessary regulation of responses to affective stimuli happens automatically in the majority of healthy individuals (Volokhov & Demaree, 2010), the failure to regulate emotions is inherent to many psychopathologies and maladaptive behaviours (Eftekhari et al., 2009). Individuals with depression exhibit a combination of decreased prefrontal activation and increased activation of limbic regions (Hamilton et al., 2012; Ochsner & Gross, 2008). This suggests that for those with depression, prefrontal regions are exhibiting poorer inhibitory control over limbic areas which are responsible for emotional experience. In accordance with this, many disorders characterised by impulsivity and a lack of inhibitory control, also exhibit a high comorbidity with emotion dysregulation, such as bulimia nervosa (Anestis et al., 2009), anxiety (Cisler & Koster, 2010; Cisler & Olatunji, 2012), depression (Joormann & Stanton, 2016), and Attention Deficit Hyperactivity Disorder (ADHD; Walcott & Landau, 2004), suggesting that when individuals do not possess the capacity to inhibit their responses, they are also more vulnerable to emotional lability. Understanding the different ways in which inhibitory control can impact emotion regulation provides insight into the variations in regulatory capacity observed in clinical and non-clinical populations.

Inhibitory control has predominantly been explored in the context of self-control where a dual task paradigm is exploited to examine the effect of prior exertion of inhibitory control on subsequent attempts to inhibit or regulate behaviour (contrast Dang, 2017; Hagger, Wood, Stiff, & Chatzisarantis, 2010, with Carter & McCullough, 2014). Exerting control on an initial task leads to a reduction in the amount of control applied to subsequent tasks resulting in heightened impulsivity (Vohs & Faber, 2007), aggression (DeWall et al., 2007), and overeating (Hofmann et al., 2007; Vohs & Heatherton, 2000). Some attempts to model these effects, such as the resource model of self-control (Baumeister et al., 1998) which depicts self-control as akin to a resource which once used needs time to replenish, have met with criticism in recent years due to an inability to identify the resource in question (Beedie & Lane, 2012; Job et al., 2010; Kurzban, 2010; Martijn et al., 2002; Schmeichel & Vohs, 2009; Tice et al., 2007), and from a failure to replicate the reported effect (Hagger et al., 2016). However, in a recent meta-analysis, Dang (2017) advises that the effect of a prior inhibitory control task on subsequent processing is apparent so long as the prior task is inherently exhausting. This meta-analysis pinpointed the colour naming Stroop task as one of the most effective, exhaustive manipulations of self-control. It is for this reason that the present study adopts the Stroop task as the means to manipulate inhibitory control. It is not yet clearly understood whether trait levels of self-control are related to an individual's ability to overcome the effects of prior exertion of inhibitory control (cf Gillebaart & de Ridder, 2015; Muraven, Collins, Shiffman, & Paty, 2005, with Imhoff, Schmidt, & Gerstenberg, 2014; Stillman, Tice, Fincham, & Lambert, 2009). For this reason, the

Self-Control Scale (SCS, Tangney, Baumeister, & Boone, 2004) is included in the present study to control for any effect of trait self-control.

Despite the challenges to the self-control literature it appears that when individuals are low in the capacity for inhibitory control, they rely instead on implicit response tendencies, impulses, and automatic behaviours (see Bertrams, Baumeister, Englert, & Furley, 2015). It is therefore not surprising that one might be more susceptible to fluctuations in mood when they are relying on impulses to guide their thoughts, feelings and behaviours. Wagner and Heatherton (2013), showed that when individuals had previously taken part in an inhibitory control task, they exhibited greater left-amygdala reactivity to negative stimuli and showed reduced connectivity between the left amygdala and prefrontal cortex (PFC). Due to both the amygdala and PFC playing an important role in the processing of emotion (Hariri et al., 2003), these findings are inherently indicative of reduced emotion regulation following the prior use of inhibitory, prefrontal processes. Furthermore, Gurney et al. (2018), found that a demanding inhibitory control task elicited subsequently heightened mood lability, in terms of experienced happiness and sadness, in response to both positive and negative mood manipulations. We therefore propose that exerting inhibitory control on a demanding task might similarly increase the subsequent degree of emotion experienced in response to the presentation of emotionally salient images.

One technique thought to contribute to effective emotion regulation is mindfulness meditation. Derived from the reflective traditions of the Buddhist religion, mindfulness encourages individuals to focus on the present moment acknowledging their thoughts, emotions, and bodily sensations in a non-judgmental acceptance, and enhanced awareness of the present reality (Brown & Ryan, 2003; Cardaciotto, Herbert, Forman, Moitra, & Farrow, 2008). In recent years mindfulness has been explained with regards to consciousness and metacognition (Jankowski & Holas, 2014; Norman, 2017), in that both mindfulness and metacognition involve an increase in attention and an awareness of one's own cognition (see Norman, 2017). Specifically, mindfulness is thought to increase sensitivity to fringe consciousness, a facet of metacognition which involves the fleeting feelings of familiarity or novelty (see Norman, 2017; Rosenstreich & Ruderman, 2017). This awareness of one's thoughts and feelings in the absence of judgment can be referred to as 'decentering' and is thought to facilitate effective emotion regulation (Bishop et al., 2004; Coffey, Hartman, & Fredrickson, 2010). Mindfulness has been shown to be beneficial for a variety of conditions linked to emotion dysregulation including hypochondriasis (McManus, Surawy, Muse, Vazquez-Montes, & Williams, 2012), depression and anxiety (Baer, 2003), maladaptive eating behaviours and obesity (Mantzios & Wilson, 2015), ADHD (Zylowska et al., 2008), and psychosis (Gaudiano & Herbert, 2006; Khoury, Lecomte, Gaudiano, & Paquin, 2013). An extensive body of research, has reported a link between mindfulness techniques and emotion regulation (see Chambers, Gullone, & Allen, 2009, for a review). Mindfulness Based Cognitive Therapy (MBCT) for instance, enables successful emotion regulation by encouraging individuals to alter their automatic or ingrained responses to distressing thoughts and images in order to diminish worry and rumination (Williams, 2008). Teper, Segal, and Inzlicht (2013), suggest that mindfulness improves emotion regulation by enhancing a sensitivity to minor changes in affective states which signal the need for inhibitory processes before the full extent of the original emotional trajectory can unfurl. Despite challenges in conceptualising the mechanism by which mindfulness influences emotion regulation, the body of research demonstrating that relationship is increasing exponentially reinforcing the value of further investigation.

Furthermore, whilst many studies of mindfulness examine lengthy interventions often lasting for a period of weeks or months (Farb et al., 2010), research has also demonstrated that the beneficial effects of mindfulness on emotion regulation can be observed even after very brief interventions lasting for a matter of minutes. Such studies have revealed decreased negativity to repetitive thoughts (Feldman, Greeson, & Senville, 2010), reduced dysphoria (Broderick, 2005) and aggression (Heppner et al., 2008), and less spider avoidance behaviour in phobic participants (Hooper, Davies, Davies, & McHugh, 2011) following a short mindfulness induction. A study by Arch and Craske (2006) demonstrated that in comparison to controls, those undergoing a short 15-minute mindfulness breathing manipulation experienced lower levels of negative affect and emotional volatility and a greater willingness to be exposed to negative images. In light of such findings, the present study proposes that a brief period of mindfulness meditation will have the general effect of increasing emotion regulation and will thus reduce the degree of positive and negative affect attributed to emotionally salient images.

In the present paper we examine the effect of two manipulations on subsequent processing of emotionally salient images. Experiment 1 investigates the effect of an inhibitory control manipulation on affective evaluations. Specifically, the degree of prior inhibitory demand is manipulated via the completion of either an easy or difficult version of a colour naming Stroop task. The effect of this manipulation on participants' emotional evaluation of positive and negative images is then examined. If challenging inhibitory tasks have the general effect of increasing subsequent emotional lability, then we should observe more extreme emotional ratings for both positive and negative images. Thus, we predict more extreme ratings of positive and negative images for those in the difficult inhibitory task condition. Experiment 2 seeks to achieve the opposing effect by exploiting a mindfulness manipulation aimed to increase emotion regulation. Specifically Experiment 2 examines the effect of a short mindfulness manipulation, in comparison to a mind-wandering procedure, on affective evaluations of the same stimuli employed in Experiment 1. If the brief mindfulness procedure has the effect of reducing emotional lability, then we should observe less extreme ratings for both positive and negative images; creating a pattern opposite to that of the inhibitory control manipulation. Thus, we predict less variability in ratings of positive and negative images for those in the mindfulness condition.

Experiment 1

Method

Participants

Participants were 120 volunteers (69 female, 51 male) aged 18-34 years (*M* = 21, *SD* = 2.06) recruited from the University of Sussex and participating in exchange for entry into a £25 prize draw. Participants were randomly assigned in equal proportions to one of two inhibitory task conditions: difficult versus easy and were naïve to the experimental hypothesis. The experiment was considered low risk and received ethical approval from the University of Sussex School of Psychology ethics committee. All participants read an information sheet and signed a consent form before the experiment began. At the end of the experiment participants were fully debriefed as to the nature of the experimental aims.

Materials

The complete set of materials and the data for both experiments has been made available on the Open Science Framework (OSF) and can be retrieved from https://osf.io/fbhej. All elements of the experiment were implemented in Matlab and run on a Pavilion DM4 computer with a 15” 60Hz monitor. Participants were seated with a viewing distance of 600mm.

Mood ratings for the emotions: happy, sad, anxious, aroused (awake/alert), and angry, were captured using a Visual Analogue Scale (VAS) ranging from ‘not at all’ to ‘extremely’. These mood ratings were captured in order to examine any changes in subjective mood which might otherwise confound or explain between group differences in the resulting picture ratings.

For the purposes of a manipulation check an additional VAS captured how mentally exhausting participants found the stroop task, i.e. “Thinking back to the earlier colour classification task, how mentally exhausting did you find it?” rated from ‘not at all’ to ‘extremely’.

Two versions of the colour-naming Stroop task were employed to manipulate inhibitory control; these were those previously found to be among the stronger manipulations for these purposes (Dang, 2017; Hagger et al., 2010).

The Self-Control Scale (SCS, Tangney, Baumeister, & Boone, 2004), a 36 item, self-report questionnaire was used to measure trait self-control.

The Five Facet Mindfulness Questionnaire (FFMQ, Baer, Smith, Hopkins, & Toney, 2006), a 39 item, self-report questionnaire was included as a measure of mindfulness.

A collection of 72 positive and 72 negative images matched for degree of valence and arousal were selected from the IAPS database. These were presented alongside a VAS capturing ratings from ‘extremely negative’ to ‘extremely positive’.

Design

The experiment exploited a between-subject design with one independent variable: inhibitory task condition. The primary dependent variables of interest were the mean ratings of positive and negative images with scores on both the SCS and FFMQ included as covariates.

Procedure

The experiment was conducted in a quiet room with the experimenter present at all times. Participants first provided demographic information (age and gender) and rated their mood using the on-screen VAS for happiness, sadness, anxiety, arousal and anger. Instructions were then provided for the inhibitory control manipulation.

Inhibitory control manipulation. Participants completed one of two versions of the colour naming task (difficult vs. easy). Those in the difficult condition completed a four-colour Stroop requiring high levels of control in order to suppress the automatic tendency to read the word in order to correctly report the colour of the text that it is written in (either Red, Green, Blue or Yellow). For example, ‘red’ written in blue must be classified as blue and not red. Participants were instructed to be as accurate as possible and keep errors to an absolute minimum. Each trial began with a fixation cross for 300ms before the colour word was presented for 1000ms. Words were displayed in ‘Arial’ font size 50. Responses were made using the number keys 1-4 with the corresponding colours presented onscreen in monochrome throughout. If participants failed to respond within one second or a wrong classification was made, then an error tone (middle C pitch) sounded. There was a total of 240 Trials with every 8 trials containing 2 trials of each colour word in a randomized order. The colour word and the text in which it was written in were the same (concordant trials) for 6 out of every 8 trials and for the remaining 2 trials the colour words were written in one of the other three colours chosen at random (discordant trials).

Those in the easy condition completed a simplified two-colour version of the task requiring no inhibition in which the colour of the text and the word presented were always the same (i.e. 'red' written in red), however the error tone still sounded if a mistake was made. The duration of the easy condition was fixed to match that of the difficult condition, irrespective of the number of trials completed.

In both conditions, the task was followed by a 1-minute break, whilst a countdown timer was presented on screen. This short break was followed by a second set of VAS mood ratings identical to the first, before the instructions for the picture evaluation trials were presented on screen.

Picture evaluation trials. Pictures were presented one at a time and rated on a VAS from 'extremely negative' to 'extremely positive'. Four blocks of 36 trials were used. Images were presented in a randomized order with each block of 36 containing an equal number of positive and negative images. Blocks were separated with a screen which instructed participants to "Please take a break. When you are ready to continue press any button to move on to the next block".

Following the picture evaluation trials, a third and final set of mood ratings were captured using the VAS and an additional VAS was used to record a measure of stroop exhaustion. Participants then completed two onscreen questionnaires (SCS, FFMQ) before being fully debriefed to the nature of the study and being thanked for their participation.

Results

Inhibitory Control Induced Mental Exhaustion

An independent t-test revealed that participants in the difficult inhibitory task condition rated the colour naming Stroop as significantly more mentally exhausting (M = 67.67, SE = 2.52) than those in the easy condition (M = 43.41, SE = 3.43) $t(108.44)$ = -5.70, $p < .001$, d =1.04.

The Effect of Prior Inhibitory Control on Mood

Whilst 5 emotions were measured as a set, our analyses focus on happiness and sadness as these were the most relevant to our intended design. In order to ascertain that the task itself did not differentially effect mood, two 2 (time: before vs. after inhibitory task) x 2 (inhibitory task condition: difficult vs. easy) mixed ANOVAs were conducted for ratings of happiness and sadness.

For ratings of happiness, there was a significant main effect of time, $F(1,118) = 34.70$, $p < .001$, $\eta_p^2 = .23$, no significant main effect of task condition, $F < 1$, and crucially, no significant interaction between time and task condition, $F(1,118) = 1.02$, $p = .315$, $\eta_p^2 = .01$. A paired t-test examining the main effect of time showed that participants rated themselves as significantly happier before ($M = 58.20$, $SE = 1.83$) versus after ($M = 47.92$, $SE = 1.96$) the Stroop task, $t(119) = 5.89$, $p < .001$, $d =0.49$.

For ratings of sadness there was no significant main effect of time, $F(1,118) = 1.09$, $p = .299$, $\eta_p^2 = .01$, no significant main effect of task condition, $F(1,118) = 2.11$, $p = .149$, $\eta_p^2 = .02$, and no significant interaction between time and task condition, $F < 1$.

Main Analysis

The effect of prior inhibitory control on the affective picture evaluations. A 2 (picture valence: positive vs. negative) x 2 (inhibitory task condition: difficult vs. easy) mixed ANOVA on mean picture ratings was conducted with SCS and FFMQ scores, and the exhaustion measure added as covariates, see Figure 13. Neither the covariate effect of FFMQ scores nor exhaustion reached significance, $F < 1$. However there was a significant interaction between picture valence and SCS scores, $F(1, 115) = 9.98$, $p = .002$, $\eta_p^2 = .08$. Post hoc bivariate correlations were used to examine this effect and showed a significant, positive correlation between SCS and positive picture ratings, $r =.24$, $p = .008$, and a significant, negative correlation between SCS and negative picture ratings, $r = -.35$, $p > .001$. Importantly, after controlling for any effect of the covariates, there was no significant main effect of picture valence, inhibitory task condition, nor a significant interaction between condition and picture valence, all $F < 1$.

Bayesian analysis was employed to assess the strength of evidence for the alternative hypothesis, H1, over the null hypothesis, H0 (Wagenmakers, Verhagen, Ly, Matzke et al., 2017). A Bayes factor of 3 or more indicates evidence for H1 over H0, below 1/3 indicates evidence for H0 over H1 and a Bayes factor between 1/3 and 3 represents data insensitivity (see Dienes, 2014). $B_{\mathrm{H}(0,\, x)}$ denotes a Bayes factor modelled as a half-normal distribution with a Mean of zero and a SD of *x* (see Dienes & McLatchie, 2017). It is hypothesised that the challenging inhibitory task will result in more extreme emotional ratings and hence there will be a larger difference between mean positive and negative picture ratings in the experimental versus the control condition. The SD for the Bayesian prior was therefore set to be twice the difference observed in the control condition (SD = 93.34). Additionally, to determine the robustness of the Bayes, a robustness region is calculated to show the range of scales which would support the same conclusion. The robustness region is notated as RR[x1, x2] where x1 is the lowest, and x2 the highest SD which results in the same conclusion.

Bayesian analysis examining the non-significant interaction between inhibitory task condition and task type provided strong evidence for the null hypothesis of no interaction between the prior exertion of inhibitory control and the subsequent lability of emotional judgements, $B_{\mathrm{H}(0,\, 93.34)} = 0.02$ RR[3.35,200].

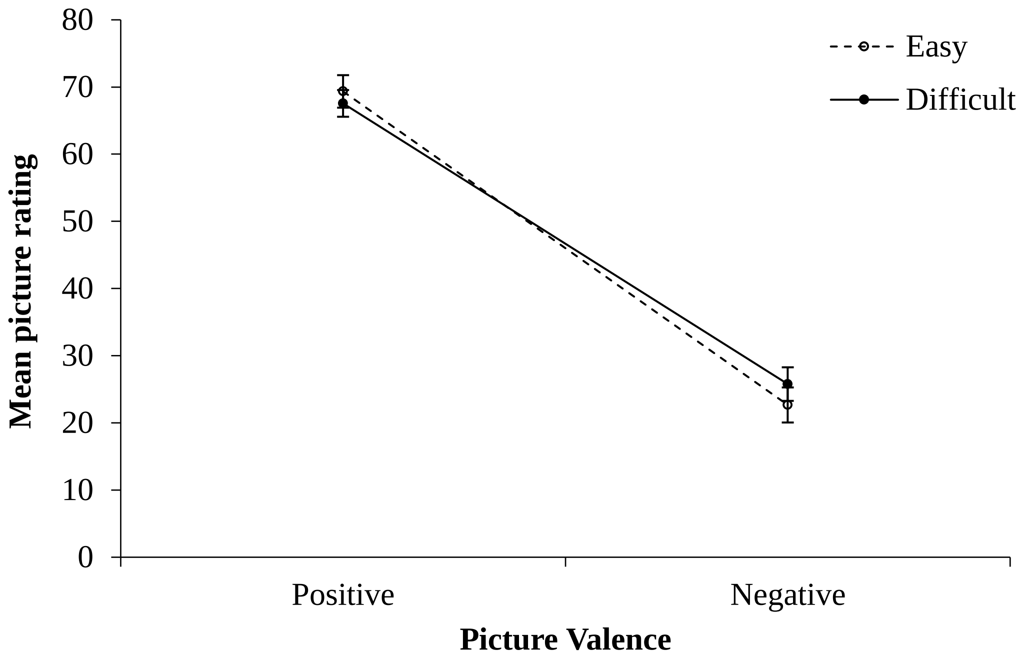

Figure 13. Mean picture rating (1 = 'extremely negative', 100 = 'extremely positive') by picture valence and inhibitory task condition (+/- 1 SEM).

The effect of prior inhibitory control on reaction times for picture evaluations. A 2 (picture valence: positive vs. negative) x 2 (inhibitory task condition: difficult vs. easy) mixed ANOVA on mean reaction times was conducted with SCS, FFMQ, and the exhaustion measure added as covariates. None of the covariates reached significance, all $F<1$. After controlling for the effect of the covariates, there was no significant main effect of picture valence, $F(1, 115) = 1.70$, $p = .196$, $\eta_p^2 = .02$, no main effect of inhibitory task condition, $F < 1$, nor a significant interaction between inhibitory task condition and picture valence, $F < 1$.

Discussion

Experiment 1 aimed to examine the effect of a prior inhibitory task on the subsequent emotional lability as reflected in affective picture evaluations. The results revealed a positive correlation between SCS scores and ratings of positive pictures and a negative correlation between SCS scores and ratings of negative pictures but no effect of FFMQ or exhaustion. Whilst participants' levels of happiness were significantly lower after the Stroop, importantly, there was no effect of inhibitory task condition meaning that both groups did not differ significantly immediately prior to rating the images. Crucially, the difficult inhibitory task was found to be more mentally exhausting than the easy task, suggesting that the manipulation was successful in creating more inhibitory demand, consistent with findings from Dang (2017). Despite this, the results revealed strong evidence for no effect of prior inhibitory challenge on subsequent ratings of affective images. If the prior use of inhibitory control has the general effect of increasing subsequent emotional lability, then more extreme ratings of positive and negative images should have been observed for those in the difficult condition. As such, the findings do not support the hypothesis and contrast results from previous literature which report higher levels of emotional reactivity in response to affective stimuli exhibited in increased amygdala reactivity (Wagner & Heatherton, 2013) following a challenging inhibitory control task.

Given the use of mindfulness procedures in reducing emotional lability in many disorders, Experiment 2 aims to examine whether variations in levels of affect attributed to picture stimuli of both positive and negative valence, is stabilised by a short mindfulness induction procedure.

Experiment 2

Method

Participants

Participants were 118 volunteers (86 female, 32 male) aged 18 to 35 years (*M* = 22.27, *SD* = 4.00) recruited from the University of Sussex and participating in exchange for entry into a £25 prize draw. Participants were randomly assigned in equal proportions to one of two conditions: mindfulness versus mind-wandering and were naïve to the experimental hypothesis. The experiment was considered low risk and received ethical approval from the University of Sussex School of Psychology ethics committee. All participants read an information sheet and signed a consent form before the experiment began. At the end of the experiment participants were fully debriefed as to the nature of the experimental aims.

Materials

All materials were identical to Experiment 1 except for the manipulation task and manipulation check. The mindfulness and mind-wandering inductions, used for the mindfulness manipulation, were presented to participants via headphones. The full scripts for the both inductions were adapted from Arch and Craske, (2006), and are available with all other materials on the OSF at: https://osf.io/fbhej/. Where the manipulation check in Experiment 1 enquired about how mentally exhausting the colour classification task was, in Experiment 2 participants used a VAS to report on engagement during the listening task. They were presented with the question, "Thinking back to the earlier listening task, how well were you able to engage with the instructions?" and provided their rating on a scale from 'not at all' to 'extremely'.

Design

The experiment used a between-subjects design with one independent variable: mindfulness manipulation condition (mindfulness vs. mind-wandering). The primary dependent variables of interest were the ratings of positive and negative images with scores on both the SCS and FFMQ again included as covariates.

Procedure

Participants were run individually in a quiet room with the experimenter present at all times. The procedure was identical to that in Experiment 1 with the exception that the inhibitory control manipulation was replaced by the mindfulness manipulation.

Mindfulness manipulation. Participants completed either a mindfulness or mind-wandering manipulation. Those in the mindfulness condition listened to a 10-minute mindfulness induction during which participants were led through a focused breathing meditation exercise encouraging a focus on the present moment and the physical sensations of breathing. Those in the mind-wandering condition listened to a 10-minute mind-wandering induction which repeatedly asked participants to think of whatever came to mind.

Results

Mindfulness Manipulation Task Engagement

An independent t-test revealed no significant difference in task engagement between those in the mindfulness (*M* = 69.67, *SE* = 2.53) and mind-wandering (*M* = 71.16, *SE* = 2.52) conditions, *t*(116) = 0.42, *p* = .678, *d* = 0.11.

The Effect of the Mindfulness Manipulation Condition on Mood

In order to ascertain that the task itself did not differentially effect mood, two 2 (time: before vs. after the manipulation) x 2 (mindfulness manipulation condition: mindfulness vs. mind-wandering) mixed ANOVAs were conducted for ratings of happiness and sadness.

For ratings of happiness, there was no significant main effect of time, $F < 1$, or task condition, $F(1,116) = 1.34$, $p = 250$, $\eta_p^2 = .01$, but a significant interaction between time and task condition, $F(1,116) = 4.62$, $p = .034$, $\eta_p^2 = .04$. Given the significant interaction, paired t-tests were conducted to examine the simple effects of time for each level of the mindfulness manipulation. Results showed that those in the mind-wandering condition rated themselves as significantly happier before (*M* = 66.90, *SE* =1.83), versus after (*M* = 62.59, *SE* = 2.39) the mind-wandering induction, *t*(59) = 2.12, *p* = .038, *d* = 0.27. However, those in the mindfulness condition showed no significant difference in their ratings of happiness before (*M* = 59.98, *SE* =2.58), versus after (*M* = 62.19, *SE* = 3.04) the mindfulness induction, *t*(57) = -0.98, *p* = .332, *d* = 0.13. The interaction was also examined using independent t-tests to investigate the simple effects of mindfulness manipulation at each time point. Results showed that before the manipulation, those in the mind-wandering condition rated themselves as significantly happier (*M* = 66.90, *SE* = 1.83), than those in the mindfulness condition (*M* = 59.98, *SE* = 2.58), *t*(103.41) = 2.19, *p* = .031, *d* = 0.41. However, after the manipulation, there was no significant difference in ratings of happiness between mind-wandering (*M* = 62.59, *SE* = 2.39) and mindfulness (*M* = 62.19, *SE* = 3.04) conditions, *t*(116) = 0.10, *p* = .918, *d* = 0.02.

For ratings of sadness there was no significant main effect of time, *F*(1,116) = 1.93, *p* = .167, η_p^2 = .02, or task condition, *F*(1,116) = 1.45, *p* = .231, η_p^2 = .01, but there was again a significant interaction between time and listening task type, *F*(1, 116) = 3.79, *p* = .054, η_p^2 = .03. Given the significant interaction, paired t-tests were again conducted to examine the simple effects of time for each level of the mindfulness manipulation. Results showed that those in the mind-wandering condition showed no significant difference in their ratings of sadness before (*M* = 18.76, *SE* =2.09), versus after (*M* = 19.54, *SE* = 2.41) the mind-wandering induction, *t*(59) = -0.52, *p* = .608, *d* = 0.07. Similarly, for the mindfulness condition, the difference between ratings of sadness before (*M* = 25.60, *SE* =2.73), versus after (*M* = 20.92, *SE* = 3.14) the manipulation failed to reach significance, *t*(57) = 1.96, *p* = .055, *d* = 0.27. Independent t-tests were conducted to examine the simple effects of mindfulness manipulation condition at each time point. Results showed that before the manipulation, those in the mind-wandering condition rated themselves as significantly less sad (M = 18.76, SE = 2.09), than those in the mindfulness condition (M = 25.60, SE = 2.73), $t(116) = -1.99$, p = .048, d = 0.37. However, after the induction, there was no difference in ratings of sadness between mind-wandering (M = 19.54, SE = 2.41) and mindfulness (M = 20.92, SE = 3.14) conditions, $t(116) = -0.35$, p = .726, d = 0.06.

Note, while these analyses reveal an unintended difference in mood between conditions at time 1, crucially they reveal no significant differences in mood between conditions at time 2 (i.e. immediately prior to rating the emotional pictures).

Main Analysis

The effect of mindfulness manipulation on the affective picture evaluations. A 2 (picture valence: positive vs. negative) x 2 (mindfulness manipulation condition: mindfulness vs. mind-wandering) mixed ANOVA on mean picture ratings was conducted with SCS, FFMQ, and the engagement measure added as covariates, see Figure 14. None of the covariates reached significance, all $p > .05$. Importantly, after controlling for the effect of the covariates, there was a significant main effect of picture valence, $F(1,113) = 22.95$, $p < .001$, $\eta_p^2 = .17$, whereby participants mean ratings reflected the positive (M = 70.50, SE = 0.70) and negative (M = 19.68, SE = 0.56) nature of the stimuli . There was also a main effect of mindfulness manipulation condition, $F(1,113) = 6.65$, $p = .011$, $\eta_p^2 = .06$, whereby those in the mind-wandering condition rated the images as more positive on average (M = 45.93, SE = 0.46) in comparison to those in the mindfulness condition (M = 44.24, SE = 0.47). However, crucially there was no significant interaction between mindfulness manipulation condition and picture valence, $F(1,113) = 2.54$, $p = .114$, $\eta_p^2 = .02$.

Bayesian analysis was again utilised to examine the strength of evidence for the null hypothesis that there was no interaction between condition type and picture valence; the same procedure was adopted as outlined in Experiment 1. The expectation was that ratings in the mindfulness condition would be less extreme than in the mind-wandering condition. As such, the prior was modelled as a half-normal distribution with a mean of 0 and a SD of half the difference observed in the control (mind-wandering) condition (SD = 26.18). The resulting Bayes Factor was less than 1/3 and thus provided strong evidence for the null hypothesis that there was no interaction between mindfulness condition and the subsequent emotional response to the valenced images, $B_{H(0, 26.18)} = 0.03$, RR[2.62, 250].

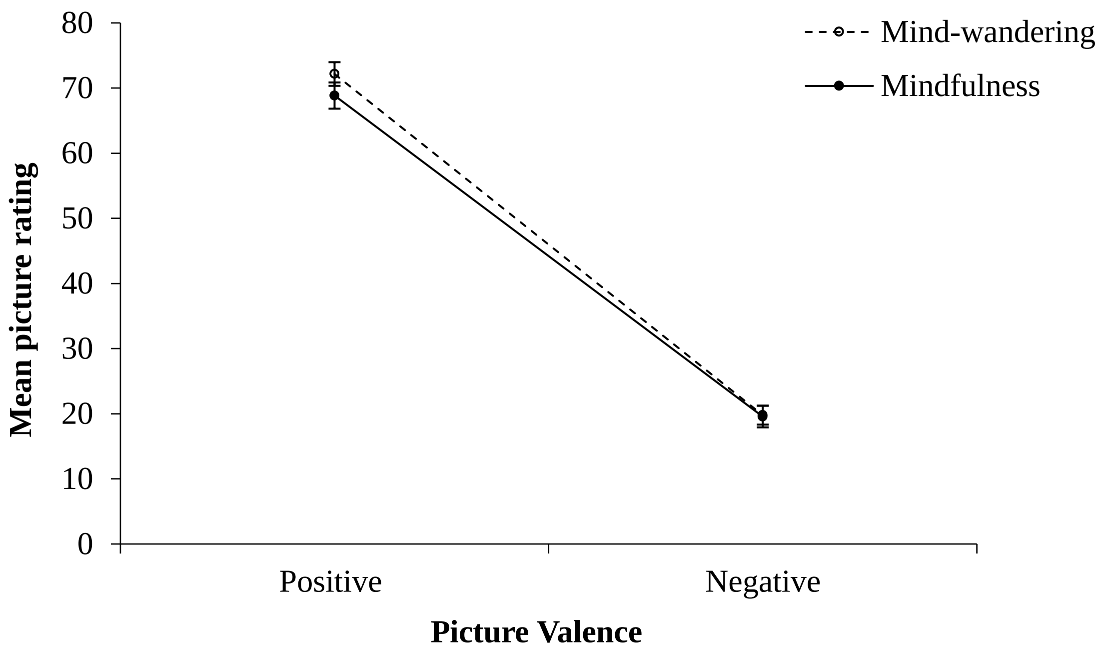

Figure 14. Mean picture rating (1 = 'extremely negative', 100 = 'extremely positive') by picture valence and induction type (+/- 1 SEM).

The effect of mindfulness on reaction times for picture evaluations. A 2 (picture valence: positive vs. negative) x 2 (induction condition: mindfulness vs. mind-wandering) mixed ANOVA on mean reaction times was conducted with SCS, FFMQ, and the engagement measure added as covariates. Consistent with Experiment 1, none of the covariates reached significance, all $p > .05$. After controlling for the effect of the covariates, there was no significant main effect of picture valence, induction condition, nor a significant interaction between induction condition and picture valence, all $F < 1$.

Discussion

Experiment 2 examined the effect of a mindfulness meditation procedure on the subsequent emotional lability as reflected in affective picture evaluations. Results showed no covariate effects of SCS, FFMQ nor task engagement. There was also no significant difference in levels of task engagement between those in the mindfulness versus mind-wandering condition, suggesting that this was not a confounding variable. Whilst the results showed an unintended significant between conditions difference in levels of happiness and sadness before the manipulation, importantly there was no significant between conditions difference in mood after the manipulation and immediately prior to rating the images. There was a main effect of both picture valence and mindfulness condition. Crucially however, there was no interaction between mindfulness manipulation condition and picture valence. If a brief mindfulness procedure has the effect of reducing subsequent emotional lability, then less extreme ratings of positive and negative images should have been observed. As such the result provide no evidence for previous research documenting a link between mindfulness and effective emotion regulation (e.g. Bishop et al., 2004; Chambers, Gullone, & Allen, 2009; Coffey, Hartman, & Fredrickson, 2010).

General Discussion

Previous research has shown that the ability to regulate emotions effectively is linked to inhibitory control (Paschke et al., 2016; Tangney et al., 2004) and is facilitated by mindfulness techniques (Bishop et al., 2004; Coffey et al., 2010). While much research has established a relationship between emotion regulation and these two factors, few have endeavoured to directly examine differences in the levels of positive and negative affect specifically attributed to emotionally valenced imagery following inhibitory demand and mindfulness manipulations. Here, we sought to address this by investigating whether an inhibitory control (Experiment 1) and mindfulness (Experiment 2) manipulation would alter the level of affect observed in emotion ratings of positive and negative valenced images. Specifically, emotion ratings were compared following either an easy versus difficult version of a colour classification Stroop task (Experiment 1) and after a mindfulness versus mind-wandering manipulation (Experiment 2). If the prior use of inhibitory control increases subsequent emotional lability, it was predicted that this would be reflected in more extreme ratings of positive and negative valenced stimuli for those in the difficult versus easy condition. Conversely, if a brief mindfulness procedure reduces subsequent emotion lability, it was predicted that less extreme ratings of positive and negative affect should have been observed for the mindfulness versus mind-wandering condition.

Consistent with previous research (Dang, 2017; Hagger et al., 2010) the manipulation of inhibitory demand in Experiment 1 proved to be effective, with the difficult version of the Stroop task being rated as significantly more exhausting than the easy version. Despite this, the results revealed no effect of prior exertion of inhibitory control on the subsequent variability in ratings of positive and negative images. The results therefore do not support the hypothesis. This contrasts with previous findings which have shown an increase in mood lability after an inhibitory challenge (e.g. Gurney et al., 2018; Wagner & Heatherton, 2013) which is thought to be due to a reliance on automatic processes to guide emotion and behaviour in the absence of adequate cognitive control (see Bertrams et al., 2015; Wagner & Heatherton, 2013).

One potential explanation for why this increase in mood lability was not reflected in individuals' ratings of valenced images, is the fact that here the responses captured affective ratings of the images themselves rather than the emotional state that they induced; as such the ratings might not reflect the availability of inhibitory resources. Although we observed no effect of the temporary reduction in inhibitory control, we report a negative correlation between trait self-control (as measured by the SCS) and negative image ratings, suggesting that those with low trait self-control perceive these images more negatively than those with high self-control. This relationship supports previous research which links a variety of psychopathologies characterised by chronically impaired inhibitory control with increased emotional experience (Eftekhari et al., 2009) potentially resulting from decreased prefrontal and increased limbic activation (e.g. Hamilton et al., 2012; Ochsner & Gross, 2008).

The manipulation check employed in Experiment 2 showed no significant difference in levels of engagement between mindfulness and mind-wandering conditions. Whilst mindfulness and mind-wandering conditions showed a significant difference in mood prior to the manipulation, crucially this difference was not present immediately prior to rating the images. Despite this, the results provided strong evidence for the null hypothesis of no effect of mindfulness meditation on the subsequent variability in ratings of positive and negative images. Therefore the results contrast those previously documenting a link between mindfulness and increased emotion regulation (Bishop et al., 2004; Coffey et al., 2010).

It could be argued that longer periods of mindfulness meditation training are needed to observe the full extent of the benefits on subsequent emotion regulation. However, previous research employing very brief periods of mindfulness meditation have compellingly shown beneficial effects on subsequent cognition and behaviour (e.g.

Arch & Craske, 2006; Broderick, 2005; Feldman et al., 2010; Heppner et al., 2008; Hooper et al., 2011) suggesting that this need not be the case. One possible explanation for our failure to observe an effect in the current study relates to the strength of the manipulation. The design utilised here sought to evaluate the extent to which the pictures influenced individuals emotionally, by examining the severity of their picture ratings. This design assumes that such ratings would reflect individuals' experienced emotion. However, the picture ratings could simply represent individuals' objective ratings of positive and negative affect rather than being reflective of their own emotional state. A future study could directly contrast affective ratings of pictures while also capturing ongoing mood ratings.

Previous research has established a relationship between chronic weakness of inhibitory control and emotion dysregulation (Paschke et al., 2016; Tangney et al., 2004). In comparison, mindfulness practice has been associated with improved emotion regulation (Bishop et al., 2004; Coffey et al., 2010). Here we examined whether a short inhibitory challenge increases emotional responses to affective stimuli and conversely, whether a brief mindfulness exercise decreases emotional responses to the same stimuli. The results provide strong evidence that contrary to effects observed in chronic conditions, a period of reduced inhibitory control does not increase emotional response. Similarly, in comparison to results observed following lengthy mindfulness training programs, we report strong evidence that a brief mindfulness exercise does not moderate emotional experience of affective stimuli.

General Discussion

Angela Gurney

University of Sussex

General Discussion

Summary of Aims

Previous work has shown the effects of prior use of inhibitory control on a variety of conscious behavioural outcomes (DeWall et al., 2007; Fischer et al., 2012; Hofmann et al., 2007; Schmeichel et al., 2003; Vohs & Faber, 2007; Vohs & Heatherton, 2000). However, as previously discussed, an important question remained unanswered. Are we more susceptible to unconscious influences when tired or exhausted from prior mental exertion? Gauging the extent of such variations is especially important to understanding how unconscious influences contribute in a variety of clinical conditions characterised by chronic mental exhaustion and impaired inhibitory control. This thesis used varied experimental methods to examine whether the effects of inhibitory control on conscious behavioural outcomes extend to include unconscious influences on cognition and behaviour.

Empirical Findings and Relationship with Previous Research

Firstly, Paper 1 sought to investigate the effect of prior inhibitory demand on the subsequent susceptibility to unconscious primes of both a neutral (Experiment 1) and reward relevant (Experiment 2) nature. Given previous findings that individuals appear to switch to a reliance on automatic implicit processes following a taxing inhibitory task (Bertrams et al., 2015; Hagger et al., 2010) we would have expected to observe greater levels of unconscious priming for those who had previously completed a demanding inhibitory control task. Furthermore, we would have expected this effect to be exacerbated in the presence of reward relevant primes due to previous findings that show an increased preference for, or consumption of unhealthy food items following prior inhibitory control (Hofmann et al., 2007; Papies & Hamstra, 2010; Papies, Stroebe, & Aarts, 2008; Vohs & Heatherton, 2000). In line with previous research

(Dang, 2017; Hagger et al., 2010), the manipulation of inhibitory control proved effective with those in the difficult condition rating the task as significantly more mentally exhausting than those in the easy condition. Despite this, the results provided substantial evidence for the null hypothesis that the degree of inhibitory control used on an initial task had no effect on subsequent susceptibility to unconscious primes. The findings suggest that consciously experienced mental demands do not directly impact on the efficacy of unconscious processing mechanisms, leaving the susceptibility to unconscious processes unaffected.

Considering these findings, Paper 2 examined whether prior inhibitory demand might influence susceptibility to an alternative source of subjectively non-volitional influence, namely hypnosis. Many theories of hypnosis highlight the role of, or alterations in, frontal executive functioning (e.g. Dietrich, 2003; Egner & Raz, 2007); that is in frontal processes required for inhibitory control. Therefore, we aimed to investigate evidence for such theories by comparing susceptibility of hypnotic suggestion following either an easy or difficult inhibitory task. Experiment 1 failed to find evidence for or against a between conditions difference in levels of mental exhaustion, limiting the scope for conclusions from the sample. Thus Experiment 2 sought to replicate the procedure used in Experiment 1 using the same analyses and a larger sample. Here a stopping rule was imposed such that participants were run until the Bayes factor for the exhaustion manipulation check provided evidence for either H1 or H0. The results showed that consistent with Paper 1, we found the inhibitory manipulation to be effective in creating a higher level of mental exhaustion in the difficult task condition. Consistent with previous research there was also evidence for a relationship between individuals' mean hypnotic response and their expectancy ratings (Kirsch, 1985), and DES scores (Kirsch & Council, 1992; Nadon, Hoyt, Register, &

Kihlstrom, 1991). Crucially however, the results provided substantial evidence that the prior exertion of inhibitory control does not affect subsequent susceptibility to hypnotic suggestion. These findings are consistent with cold control theory of hypnosis (Dienes, 2012; Dienes & Perner, 2007) which maintains that any disruption of frontal function would leave hypnotisability unaffected unless that disruption extended to the ability to form accurate metacognitive representations. This is similarly consistent with the findings of Paper 1, where prior inhibitory challenge left subjective thresholds of awareness unaltered; again, indicating that higher-order thoughts were uninfluenced.

In light of previous work showing that the capacity for inhibitory control relates to the ability to successfully regulate emotions (Layton & Muraven, 2014; Pashke et al., 2016; Tangney et al., 2004; Wagner & Heatherton, 2013), Paper 3 sought to investigate whether a direct manipulation of inhibitory control would affect subsequent mood lability observed within a behavioural (Experiment 1) and fMRI (Experiment 2) design. It was predicted that the behavioural results from Experiment 1 would reflect a greater change in mood following mood induction for those who had performed the difficult inhibitory task, due to a reduced capacity for emotion regulation. Consistent with previous research (e.g. Dang, 2017; Hagger et al., 2010), Experiment 1 found the manipulation of inhibitory demand to be effective with participants rating the difficult task as significantly more exhausting than the easy version. Crucially the results showed that prior inhibitory demand resulted in a period of increased mood lability, observed in participants ratings of positive and negative emotion, following either a positive or negative mood manipulation. Given the role of regions of the executive control network (ECN) in monitoring cognitive influences on emotion (Stevens et al., 2011), and the importance of the default mode network (DMN) in self-related emotion and introspection in those with depression (Greicius et al., 2007), it was predicted that the fMRI results from Experiment 2 would show significant changes in ECN and DMN activation and connectivity following the prior use of inhibitory control. In contrast to Experiment 1, no significant difference in behavioural ratings of mental exhaustion were observed; Bayesian analyses indicated that the results were insensitive. The fMRI results revealed a significant increase in activation of regions involved in both of the hypothesised networks (ECN and DMN) after the inhibitory manipulation, however this was observed for both task conditions suggesting no significant effect of prior inhibitory control on cortical activity. Furthermore, we found no differences in resting state network (RSN) connectivity and thus were unable to replicate previous work showing a profile of decreased frontal connectivity following prior inhibitory control (Wagner & Heatherton, 2013). Importantly, examining the mean exhaustion levels for both conditions revealed that each showed levels of exhaustion equivalent to the difficult condition in Experiment 1 (mental exhaustion rated as > 60%). If being in the context of an fMRI scanner resulted in both tasks eliciting high levels of mental exhaustion, then the results from both conditions may reflect prior inhibitory demand on subsequent neural activation. However, viewing the results in this manner effectively removes any control group, preventing strong conclusions from being drawn.

Paper 4 sought to examine whether the period of increased mood lability following prior inhibitory control (as observed in Paper 3, Experiment 1) would be similarly reflected in valence ratings of images, and whether a brief mindfulness manipulation would have the opposing effect of reducing the degree of valence attributed to the same images. In Experiment 1, participants were asked to rate images in terms of positive and negative valence after either an easy or difficult inhibitory task. Crucially, the difficult inhibitory task was experienced as significantly more exhausting than the easy version. Despite this, we found substantial evidence that prior inhibitory control had no effect on the subsequent emotion ratings of positively and negatively valenced images. Due to previous findings that mindfulness facilitates successful emotion regulation (Bishop et al., 2004; Coffey, Hartman, & Fredrickson, 2010), Experiment 2 examined whether a brief mindfulness manipulation would reduce the extremes of emotion attributed to the same set of emotionally valenced stimuli. However, as in Experiment 1, there was strong evidence that the manipulation had no influence on the emotion ratings of the positive and negative images. These findings suggest that the perception of the emotional stimuli is not influenced by the degree to which inhibitory capacity is compromised, or by a brief mindfulness manipulation.

Throughout the course of this thesis, we examined the effect of mental exhaustion arising from prior use of inhibitory control on susceptibility to unconscious influences. We report an effect of prior inhibitory control on subsequent mood lability in response to a consciously presented piece of music. However, taken together, the results presented herein provide the novel contribution that mental exhaustion arising from prior inhibitory control, does not appear to affect unconscious cognitive processes such as subliminal priming and hypnosis. These unconscious influences are discussed further in the next section with regards to the degree to which they can be considered ‘unconscious’ and the potential reasons why mental exhaustion does not appear to affect susceptibility to these processes.

Unconscious Influences

In the introduction to this thesis, we defined the unconscious as an absence of meta-awareness; for example, where there is a dissociation between subjective reports and influence on behavioural measures. Here, we will discuss each paper in turn in order to examine the effect of inhibitory control on the different degrees of (un)conscious awareness explored. Paper 1 most directly examines unconscious processing due to the implementation of the stem completion task in examining susceptibility to subliminal priming. In line with previous research employing the stem completion paradigm (e.g. Perrig & Eckstein, 2005; Tiggemann, Hargreaves, Polivy, & McFarlane, 2004), here the stimuli are believed to be unconscious when participants report being unable to consciously discern the words presented (i.e. they are below their subjective threshold of awareness) but it influences their subsequent choice of word completion. Despite a significant priming effect, we observed no effect of a challenging inhibitory control task on subsequent susceptibility to unconscious priming suggesting no effect of mental exhaustion on unconscious influences. One reason for the absence of any effect of prior inhibitory control could be due to the unconscious nature of the stimuli; that is, it is likely that priming elicits automatic responses which do not necessitate conscious awareness or effortful control.

Similarly, in Paper 2 we examined the effect of prior inhibitory control on subsequent susceptibility to hypnosis. Whilst hypnosis is presented consciously and thus cannot be considered as a purely unconscious process, it is experienced as subjectively non-volitional; that is, individuals lack a conscious awareness that they themselves are carrying out the suggested action. Here we observed no effect of mental exhaustion arising from prior inhibitory control on hypnotic response. In a similar manner to subliminal priming, this suggests that hypnosis elicits responses which appear to function outside of subjective conscious awareness and perhaps do not necessitate effortful control.

In Paper 3 we examined a different type of unconscious process; namely we examined emotion regulation which is often thought to happen unconsciously in response to consciously perceived stimuli (Koole & Rothermund, 2011). Here, whilst the music was presented consciously, participants were given no indication of the experimental aim or the need for emotion regulation and thus were thought to be responding automatically to the music with no conscious awareness of their need for emotional control. Interestingly, we observed an increase in mood lability following the prior use of inhibitory control suggesting that mental exhaustion arising from inhibitory control affects subsequent capability for emotion regulation. Consequently, it appears that there is a depleting effect of mental exhaustion on some unconscious processes but arguably only when such cognitions require a degree of regulation or self-control.

Paper 4 examined a similar concept, namely we studied whether any heightened mood lability following prior inhibitory control might alter the perception of consciously perceived emotionally valenced stimuli. However, we found no effect of inhibitory control on valence ratings of both positive and negative stimuli. We conclude that this is likely due to the nature of the ratings involved such that they were concerned with the emotional valence of the stimuli themselves rather than a rating of participants' mood and thus likely did not reflect the need for any conscious effort or control.

Thus, whilst mental exhaustion affects some aspects of cognition which require a degree of unconscious processing (i.e. emotion regulation) it does not appear to affect other unconscious influences such as subliminal priming below the subject threshold and hypnotic response. One explanation for this could involve differing demands for self-control. Whilst emotion regulation requires some form of control (either conscious or unconscious), responses to hypnosis and subliminal priming potentially happen without the need for self-control and thus likely would not be affected by an impaired ability for executive control or response inhibition. Thus, whilst self-control itself happens both consciously and unconsciously (Fishbach & Shen, 2014; Muraven, 2012), our findings suggest that the temporary depletion of inhibitory control affects only those processes which require a degree of effortful regulation or inhibition of responses to consciously presented stimuli. These findings are discussed further below in relation to the different theories of self-control.

Implications for Models of Self-control

Whilst evaluating the different theories of self-control was not the primary objective of the present research, it is interesting to consider how the different models of self-control might attempt to account for the various findings presented in this thesis. In terms of Baumeister, Bratslavsky, Muraven, and Tice's (1998) resource model, prior inhibitory control is thought to deplete the resources necessary for subsequent attempts at inhibitory control. When considering the absence of an effect of the prior inhibitory task on unconscious priming in Experiment 1, the resource model might simply posit that there are no inhibitory processes operating in unconscious priming; hence depleting inhibitory or executive control resources could not be expected to have an effect. This would be consistent with early research which characterised unconscious priming as an automatic process which requires no intention to be initiated (Posner & Snyder, 1975). Similarly, the absence of an effect of impaired inhibitory control on hypnotic response might be viewed as support for theories which do not consider inhibition or alterations in frontal executive functions as a necessary component of hypnosis (such as the expectancy theory, Kirsch, 1985). In Paper 3, we observed increased mood lability following prior inhibitory control. This result fits well with the resource model of self-control and can be interpreted as resulting from a reduced capacity to regulate emotion due to the necessary resources being depleted by the initial exertion of self-control. Whilst this increase in mood lability was not reflected in individuals' ratings of valenced images (Paper 4), this could be due to the fact that the responses captured affective ratings of the images themselves rather than the emotional state that they induced; in which case the ratings would not be expected to reflect the availability of inhibitory resources.

According to the process model of self-control (Inzlicht & Schmeichel, 2012), failures to inhibit responses following prior inhibitory control are understood to stem from a change in motivation which shifts attention away from the need for control and toward rewards. From this perspective, it could be argued that neither unconscious priming nor hypnosis are inherently rewarding and as such individuals are not any more motivated to attend to these tasks following prior inhibitory control. The process model is able to account for the increased mood lability observed in Paper 3 by suggesting that the initial exertion of inhibitory control leads individuals to be more motivated to seek reward through absorption in the music. Whilst the rewards associated with positive music are perhaps more immediately recognisable, it has been demonstrated that individuals similarly take enjoyment from negative emotions evoked by music (Garrido & Schubert, 2011). In the case of positively and negatively valenced images, perhaps these did not elicit the same reward seeking observed for music. This could simply be due to the pictures not being inherently rewarding or enjoyable, or that the ratings were reflective of the images rather than any effect they had on mood, as outlined above.

Kurzban et al.'s (2013) opportunity cost model states that mental exhaustion arising from inhibitory control acts as a signal to cue the reallocation of executive processes to a lower cost/more beneficial task. Applied to Paper 3, this theory might argue that the inhibitory task causes the reallocation of processes towards mind-wandering and absorption rather than the more demanding emotion regulation, resulting in the increased mood lability. Considering the absence of effects in unconscious priming, hypnosis, and affective ratings, an advocate of the opportunity cost model might hold that none of these activities are inherently rewarding or demanding and as such there would be no motivation to allocate or withdraw executive processes in these contexts.

Finally, Heatherton and Wagner's (2011) balance model states that self-control fails when frontal executive processes are disrupted. This model can readily account for the increased mood lability observed in Paper 3, as it would hold that the prior inhibitory task impairs the frontal inhibitory capacity which would otherwise be employed to achieve mood regulation. However, given the inhibitory manipulation failed to result in a significant difference in mental exhaustion when employed in the fMRI experiment we are unable to provide further empirical evidence of differences in frontal activation. The balance model can also account for the finding that hypnotic response is not altered by the prior use of inhibitory control provided one endorses a model of hypnosis that is not based on frontal disinhibition, e.g. expectancy theory (Kirsch, 1985) or Cold Control Theory (Dienes, 2012; Dienes & Perner, 2007).

Implications for Mental Health and Emotion Regulation

As discussed in the introduction to this thesis, impaired self-control is associated with a higher incidence of psychopathological symptoms (see de Ridder, Lensvelt-Mulders, Finkenauer, Stok, & Baumeister, 2011, for a review), health risk behaviours (Wills et al., 2007), poorer inhibition of negative emotions (Kieras et al., 2005), lower academic success (Duckworth & Seligman, 2005) and is thought to contribute to many challenges faced by society such as debt, obesity, criminality, racial discrimination, and substance abuse (Inzlicht & Schmeichel, 2012). Thus, understanding the extent to which our capacity for inhibitory control affects how we respond to unconscious influence is especially pertinent to furthering our understanding of how unconscious influences affect those with clinical conditions which are characterised by chronically impaired inhibitory control.

GENERAL DISCUSSION

The results from Papers 1, 2 and 4 (Experiment 1) provide evidence that a reduced capacity for inhibitory control should not alter individuals' responses to influences such as unconscious priming, hypnosis, or alter their perception of emotionally valenced stimuli. Among other applications, hypnosis has been shown to be effective for the cessation of smoking (Elkins, Marcus, Bates, Rajab, & Cook, 2017), easing insomnia (Galovski et al., 2016), and lessening the symptoms of anxiety and depression (Heap, 2012). Whilst it has yet to be shown whether a distinctively hypnotic component is responsible for all these effects, it is arguably reassuring that those suffering with impaired inhibitory control should be no less receptive to these beneficial effects. On the contrary, we report a negative correlation between hypnotic responding and trait self-control which suggests that those with chronically impaired self-control could be more receptive to these potential benefits.

The results from Paper 3 highlight the important contribution of effective inhibitory control in maintaining mood stability. Whilst many strategies are already aimed at or involved in increasing self-control, the extent to which improved self-control is the source of primary benefit taken from these therapies is, as yet, unknown. Consistent with this approach, mindfulness based therapies are thought to promote mental health by increasing self-control and thereby decreasing negative rumination and impulsive maladaptive behaviours, and increasing the capacity for effective emotional regulation (see Baer, 2003, for a meta-analysis). A study focusing on employing mindfulness to combat the effects of inhibitory control 'depletion' reported that those who partook in meditation following an inhibitory control task subsequently performed as well as those who had not previously exerted control (Friese et al., 2012). Such findings suggest that employing mindfulness strategies following self-control could decrease individuals' tendency toward increased mood lability in a state of ego-depletion. Similarly, neuroimaging studies indicate that cognitive therapy for depression and anxiety function by simultaneously reducing hyper-activation of subcortical regions responsible for emotion generation and increasing activation of higher-order cortical regions associated with mental control (Clark & Beck, 2010).

The findings from Paper 3 also fit well with the mood-as-input hypothesis (see Meeten & Davey, 2011; Startup & Davey, 2001) which has been used to successfully explain a range of perseverative behaviours in psychopathologies (see MacDonald & Davey, 2005; Hawksley & Davey, 2010; Meeten & Davey, 2011; Startup & Davey, 2001, 2003; Watkins & Mason, 2002). Previous work has demonstrated that individuals are more likely to attend to their mood and use it as a source of information under increased cognitive load (Schwarz et al., 1987; Siemer & Reisenzein, 1998), especially during a state of negativity when they have a desire to repair their mood (see Schwarz & Clore, 1983). The findings presented here indicate that mental exhaustion and the reduced capacity for control arising from prior inhibition may have a similar effect of increasing reliance on mood as a source of information and a vulnerability to mood manipulations.

Finally, whilst impulsivity and emotional lability appear to co-exist in pathological states (see Eftekhari, Zoellner, & Vigil, 2009) here, trait measures of anxiety, depression and impulsivity were unrelated to emotional lability (Paper 3). This may be due to the nature of the sample employed with results differing for clinical populations. Alternatively, relationships between these personality measures and mood lability may be unrelated to transient changes in mood of the sort achieved in our study.

General Limitations and Future Directions

Dang (2017), highlights the importance of the effectiveness of the inhibitory task as paramount to being able to subsequently examine the effects of mental exhaustion arising from inhibitory control. In Papers 1, 2, and 4 the Stoop was used as the inhibitory control task and (with the exception of Experiment 1 in Paper 2) was shown to be successful in creating a higher level of mental exhaustion for those undertaking the difficult task, consistent with previous research (Bray et al., 2008; Govorun & Payne, 2006; Webb & Sheeran, 2003). Bearing this in mind, it should have been possible to observe effects of mental exhaustion on subsequent behaviours should they exist. Paper 3 utilised the e-crossing task which, at the time of employing the task, had been identified as one of the strongest inhibitory control manipulations (Hagger et al. 2010). In Experiment 1 this showed to be effective in producing a significant difference in levels of task related mental exhaustion. However, as mentioned above, the same difference was not observed in the fMRI context of Experiment 2. Instead we observed that both conditions gave an average rating of mental exhaustion which were similar to that observed in the difficult inhibitory condition in Experiment 1. This suggested that both of the e-crossing tasks were experienced as similarly exhausting. In order to allow for conclusions regarding neural activation and connectivity underlying the effect of prior inhibitory control, it is therefore imperative that future research test the effectiveness of the inhibitory control tasks (e.g. Stroop, e-crossing, emotion video) in order to find a task that transfers most appropriately into the scanner environment. This is especially important considering recent replication failures in the self-control literature (Hagger et al., 2016).

The present research sought to assess the effect of prior inhibitory demand on subsequent susceptibility to unconscious influences. Arguably the most direct test of this is observed in Paper 1 which utilised a stem completion task to assess levels of unconscious priming following an inhibitory control manipulation. While not explicitly an unconscious process, Paper 2 examined hypnosis which is experienced as subjectively non-volitional. Similarly, whilst the music-based mood manipulations employed in Paper 3 were presented consciously, we investigate their influence on emotion regulation which can be elicited in the absence of subjective awareness (see Koole & Rothermund, 2011). This same approach was employed for Paper 4 in which the stimuli used were conscious, and we sought to examine any influence of mental exhaustion on the perception of emotional valence.

There are alternative experimental paradigms that it was not possible to employ within the scope of this thesis, but which may prove to be more sensitive to unconscious influences and, as such, might reasonably be explored in future research. One such example would be to assess the effects of a prior inhibitory challenge on unconscious attentional shifts. This could be achieved using an unconscious dot-probe task exploiting back-masking or continuous flash suppression to suppress neutral and rewarding stimuli. It remains to be established whether states of mental exhaustion arising from prior inhibitory control alter such pre-conscious attentional biases.

Reproducibility

Over the last decade a crisis of confidence in the field of psychological science has resulted from failures to replicate, questionable research practices, publication bias, and a lack of willingness to share data (Pashler & Wagenmakers, 2012). Consequently, in recent years, replicability has been identified as of chief importance within the empirical sciences (Schmidt, 2009). The Reproducibility Project by the Open Science Collaboration (Aarts et al., 2015) closely replicated 100 studies selected from leading journals and found that less than 40 were successfully replicated, further impressing the need for independent replications (Asendorpf & Conner, 2012). Publication bias, which refers to the higher likelihood for papers to be published if they report significant results (Bishop & Thompson, 2016) can contribute to the reproducibility crisis by encouraging a tendency to chase statistically significant (Stahel, 2016) and discard non-significant results (see Amrhein, Korner-Nievergelt, & Roth, 2017). With orthodox statistics, a non-significant result is uninformative and can result in being misinterpreted as evidence against a theory, or wrongly discarded when it could offer evidence for the null hypothesis (see Dienes, 2014). Bayesian statistics overcome this issue by distinguishing between a statistically non-significant result which is a product of data insensitivity and a non-significant result which provides evidence for the null hypothesis (Dienes, 2014). Furthermore, Verhagen and Wagenmakers (2014) provide a protocol for using Bayes to determine whether an attempt at replication has been successful or not by modelling the alternative hypothesis of the replication study on the posterior distribution of the effect observed in the original experiment. Crucially, this process is able to detect effects of the same size as obtained in the original study and can be applied to multiple replications (see Verhagen & Wagenmakers, 2014).

This thesis embraces current practices to promote data transparency and replicability. We employ Bayesian statistics to determine whether statistically non-significant results provide evidence for and against the null hypothesis. Further we employ the replication procedure outlined in Verhagen and Wagenmakers (2014) in Paper 2. We also provide links to the data and experimental materials stored on the Open Science Framework, the core purpose of which is to promote "openness, integrity, and reproducibility of scientific research" (Center for Open Science, 2013, p.1).

Conclusion

Converging methods are utilised in the current thesis to provide the novel contribution that mental exhaustion arising from the prior use of inhibitory control processes, has no effect on subsequent susceptibility to unconscious influences arising from unconscious priming and hypnosis, and no effect on the degree of emotion attributed to positively and negatively valenced images. Despite no significant differences in neural activation or connectivity being observed between inhibitory task conditions, mental exhaustion arising from inhibitory control does appear to result in a period of increased mood lability suggesting that individuals either find it more challenging to regulate their emotions, or do not attempt to use inhibitory processes for emotion regulation following prior inhibitory demand. The results suggest that those with conditions characterised by chronically impaired inhibitory capacity may be more susceptible to unconscious influence on their mood state but should be no more susceptible to unconscious priming and no less receptive to the potential therapeutic effects of hypnosis.

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Appendix A: Word stimuli employed in Paper 1

Visual Threshold	Stem Completion Experiment 1		Stem Completion Experiment 2	
			Reward	*Neutral*
red	shape	debit	bacardi	earlobe
green	stupid	offend	baguette	sanctify
blue	asset	muscle	banana	endure
yellow	talent	bound	barbeque	transpire
orange	morgue	armour	batter	raving
black	appear	goose	berry	goose
grey	deter	wages	biscuit	quarrel
purple	hollow	elect	bread	refer
pink	verify	marry	burger	expire
brown	which	cheese	candy	freak
one	birch	racer	caramel	beehive
two	yeast	cough	cheese	relate
three	vacant	grass	chips	dried
four	glean	orgasm	chocolate	narrative
five	scurry	street	cocoa	wedge
six	ballet	victim	coffee	object
seven	friend	horse	cream	blame
eight	tender	awake	crisps	untidy
nine	salary	behave	croissant	calloused
ten	visit	crash	curry	elect
eleven	native	speed	dessert	rapport
twelve	affair	common	dinner	danger
thirteen	squid	secure	feast	slave
fourteen	triple	clear	flake	debit
fifteen	notice	thump	galaxy	famine
sixteen	relate	emblem	honey	vague
seventeen	patch	change	lager	litre
eighteen	famine	click	lemon	width
nineteen	mutate	metro	lunch	limit
twenty	bride	germs	mango	feral
	panda	endure	martini	pollute
	adorn	sound	melon	hinge
	define	locate	meringue	dismount
	afresh	insert	nougat	wangle
	annoy	threat	orange	native
	single	diary	picnic	triple
	oracle	refer	pudding	vicious
	dried	raisin	raisin	mutate
	trust	estate	roast	venus

aerial	known	salmon	vessel
galaxy	alley	sambuca	offense
expire	alive	sausage	fatigue
risen	guilty	scone	waive
scope	rustle	sherbet	hydrant
cable	trough	sorbet	velour
global	astute	sweets	vacant
garlic	latte	tortilla	abdicate
motive	gentle	truffle	verbose
pasta	admit	vanilla	abiding
raving	drone	waffle	wallow

Appendix B: Word stimuli with frequency data for Paper 1 Experiment 2

Stem	Reward	Frequency	Stem	Neutral	Frequency	Number of Letters
bac	bacardi	23	ear	earlobe	12	7
bag	baguette	19	san	sanctify	13	8
ban	banana	511	end	endure	511	6
bar	barbeque	11	tra	transpire	22	9
bat	batter	148	rav	raving	166	6
ber	berry	461	goo	goose	479	5
bis	biscuit	552	qua	quarrel	552	7
bre	bread	3621	ref	refer	3720	5
bur	burger	210	exp	expire	218	6
can	candy	360	fre	freak	337	5
car	caramel	71	bee	beehive	74	7
che	cheese	2504	rel	relate	2555	6
chi	chips	1789	dri	dried	1730	5
cho	chocolate	1931	nar	narrative	1672	9
coc	cocoa	479	wed	wedge	400	5
cof	coffee	6213	obj	object	6135	6
cre	cream	3099	bla	blame	2973	5
cri	crisps	353	unt	untidy	376	6
cro	croissant	28	cal	calloused	27	9
cur	curry	526	ele	elect	526	5
des	dessert	300	rap	rapport	293	7
din	dinner	5858	dan	danger	5755	6
fea	feast	849	sla	slave	858	5
fla	flake	262	deb	debit	259	5
gal	galaxy	605	fam	famine	633	6
hon	honey	1413	vag	vague	1432	5
lag	lager	497	lit	litre	502	5
lem	lemon	1190	wid	width	1128	5
lun	lunch	4850	lim	limit	4848	5
man	mango	110	fer	feral	119	5
mar	martini	114	pol	pollute	109	7
mel	melon	198	hin	hinge	203	5
mer	meringue	57	dis	dismount	67	8
nou	nougat	10	wan	wangle	18	6
ora	orange	2585	nat	native	2568	6
pic	picnic	632	tri	triple	670	6
pud	pudding	837	vic	vicious	840	7
rai	raisin	29	mut	mutate	27	6
roa	roast	510	ven	venus	510	5
sal	salmon	1403	ves	vessel	1382	6

sam	sambuca	1	off	offense	8	7
sau	sausage	497	fat	fatigue	480	7
sco	scone	145	wai	waive	138	5
she	sherbet	24	hyd	hydrant	14	7
sor	sorbet	34	vel	velour	24	6
swe	sweets	726	vac	vacant	785	6
tor	tortilla	33	abd	abdicate	45	8
tru	truffle	25	ver	verbose	31	7
van	vanilla	176	abi	abiding	196	7
waf	waffle	87	wal	wallow	60	6

Appendix C: Word stimuli with alternative completions Paper 1 Experiment 2

Reward Stimuli				*Neutral Stimuli*			
Stem	Target Word	Alternative Completions		Stem	Target Word	Alternative Completions	
bac	bacardi	backing	backfire	ear	earlobe	early	earnest
bag	baguette	baggage	bagpipe	san	sanctify	sanction	sanctuary
ban	banana	band	bangle	end	endure	endorse	endless
bar	barbeque	barber	barge	tra	transpire	transit	transient
bat	batter	baton	batch	rav	raving	ravage	ravel
ber	berry	beret	bereaved	goo	goose	good	goon
bis	biscuit	bishop	bison	qua	quarrel	quantity	quandary
bre	bread	break	breath	ref	refer	refine	refrigerate
bur	burger	burden	burglar	exp	expire	express	export
can	candy	canal	canary	fre	freak	free	freedom
car	caramel	career	carbon	bee	beehive	beetle	beech
che	cheese	cheek	cheerful	rel	relate	release	relationship
chi	chips	chief	chilly	dri	dried	drive	drily
cho	chocolate	choice	choke	nar	narrative	narrow	narrate
coc	cocoa	cocaine	cocoon	wed	wedge	wedding	Wednesday
cof	coffee	coffin	coffer	obj	object	objective	objector
cre	cream	crease	creep	bla	blame	black	blade
cri	crisps	criminal	cricket	unt	untidy	until	untold
cro	croissant	crocus	crochet	cal	calloused	calendar	calico
cur	curry	current	curtsey	ele	elect	electricity	electrode
des	dessert	despite	desperate	rap	rapport	rapid	rapt
din	dinner	dingy	dinghy	dan	danger	danger	dance
fea	feast	feature	fearful	sla	slave	slang	slap
fla	flake	flag	flair	deb	debit	debris	debate
gal	galaxy	gallant	gallery	fam	famine	fame	familiar
hon	honey	honour	honest	vag	vague	vagrant	vagabond
lag	lager	lagging	lagoon	lit	litre	literal	literacy
lem	lemon	lemming	lemur	wid	width	wide	widen
lun	lunch	lunge	lung	lim	limit	limpet	limp
man	mango	manicure	manager	fer	feral	ferocious	ferment
mar	martini	market	margin	pol	pollute	polio	polite
mel	melon	mellow	melancholy	hin	hinge	hinder	hindsight
mer	meringue	merge	mercury	dis	dismount	disciple	disco
nou	nougat	nourish	noun	wan	wangle	wand	wander
ora	orange	oracle	orator	nat	native	nature	nation
pic	picnic	pictorial	piccolo	tri	triple	tripod	trivial
pud	pudding	puddle	pudgy	vic	vicious	vicar	vicinity
rai	raisin	rain	raise	mut	mutate	mutilate	mutation

roa	roast	roam	road	ven	venus	veneer	venal
sal	salmon	salary	saliva	ves	vessel	vestige	vestry
sam	sambuca	sample	samaritan	off	offense	offend	offensive
sau	sausage	sauna	saunter	fat	fatigue	fate	fatality
sco	scone	scold	score	wai	waive	wail	waif
she	sherbet	shed	sheath	hyd	hydrant	hydraulic	hydrangea
sor	sorbet	sorrow	sort	vel	velour	velvet	velocity
swe	sweets	swede	sweep	vac	vacant	vacate	vacuum
tor	tortilla	torture	torso	abd	abdicate	abduct	abdomen
tru	truffle	trudge	trumpet	ver	verbose	verbatim	verb
van	vanilla	vandal	vanity	abi	abiding	ability	abide
waf	waffles	wafer	waft	wal	wallow	wallet	wallaby

Appendix D: Text employed for e-crossing task in Paper 3

Dinno

Page 2

Horn's Parallel Analysis

The question of the number of components or factors to retain is critical both for reducing the analytic dimensionality of data, and for producing insight as to structure of latent variables (cf. Velicer & Jackson, 1990). Guttman (1954) formally argued that because in PCA total variance equals the number of variables P, in an *infinite* population a theoretical lower bound to the number of true components is given by the number of components with eigenvalues greater than one. This insight was later articulated by Kaiser as a retention rule for PCA as the 'eigenvalue greater than one' rule (Kaiser, 1960) which has also been called the 'Kaiser rule' (cf. Lance et al., 2006), the 'Kaiser-Guttman' rule (cf. Jackson, 1993), and the 'K1' rule (cf. Hayton et al., 2004). Assessing Kaiser's prescription, Horn observed that in a *finite sample* of *N* observations in *P* measured variables of uncorrelated data, the eigenvalues from a PCA or FA would be greater than and less than one, due to "sample- error and least squares bias." Therefore, Horn argued, when making a component-retention decision with respect to observed, presumably correlated data of size *N* observations by *P* variables, researchers would want to adjust the eigenvalues of each factor by subtracting the mean sample error from a "reasonably large" number *K* of uncorrelated $N \times P$ data sets, and retaining those components or factors with adjusted eigenvalues greater than one (Horn,
1965). Horn also expressed the PA decision criterion in a mathematically equivalent way, by saying that a researcher would retain those components or factors whose eigenvalues were larger than the mean eigenvalues of the *K* uncorrelated data sets. Both these formulations are illustrated in Figure 1 which represents PA of a PCA applied to a simulated data set of 50 observations, across 20 variables, with two uncorrelated factors, and %50 total variance.

Ironically, PA has enjoyed both a substantial affirmation in the methods literature for its performance relative to other retention criteria, while at the same time being one of the least often used methods in actual empirical research (cf. Hayton et al., 2004; Patil et al., 2008; Thompson & Daniel, 1996; Velicer et al., 2000). Methods papers making comparisons between retention decisions in PCA and FA have tended to ratify the idea that PA outperforms all other commonly published component retention methods, particularly the commonly reported Kaiser rule and scree test (Cattell, 1966) methods. Indeed, the panning of the eigenvalue greater than one rule has provoked harsh criticism: "The most disparate results were obtained… with the [K1] criterion…" (Silverstein, 1977, page 398) "Given the apparent functional relation of the number of components retained by Kl to the number of original variables and the repeated reports of the method's inaccuracy, we cannot recommend the Kl rule for PCA." (Zwick & Velicer, 1986, page 439) "…the eigenvalues- greater-than-one rule proposed by Kaiser… is the result of a misapplication of the formula for internal consistency reliability." (Cliff, 1988, page 276) "On average the [K1] rule overestimated the correct number of factors by 66%. This poor performance led to a recommendation against continued use of the [K1] rule." (Glorfeld, 1995, page 379) "The [K1] rule was extremely inaccurate and was the most variable of all the methods. Continued use of this method is not recommended" (Velicer et al., 2000, page 26). In an article titled "Efficient theory development and factor retention criteria: Abandon the 'eigenvalue greater than one' criterion" Patil et al. (2008) wrote on pages 169–170 "With respect to the factor retention criteria, perhaps marketing journals, like some journals in psychology, should
recommend strongly the use of PA or minimum average partial and not allow the eigenvalue greater than one rule as the sole criterion. This is essential to avoid proliferation of superfluous constructs and weak theories." More recent methods include the root mean square error adjustment which evaluates successive maximum likelihood FA models in a progression from zero to some positive number of factors for model fit (Browne & Cudeck,
1992; Steiger & Lind, 1980), and bootstrap methods that account for sampling variability in the estimates of the eigenvalues of the *observed* data (Lambert, Wildt & Durand, 1990), but have yet to be rigorously evaluated against one another and other retention methods. Recent

Appendix E: BOLD contrast effect sizes for significant clusters in masked post>pre analyses of Paper 3

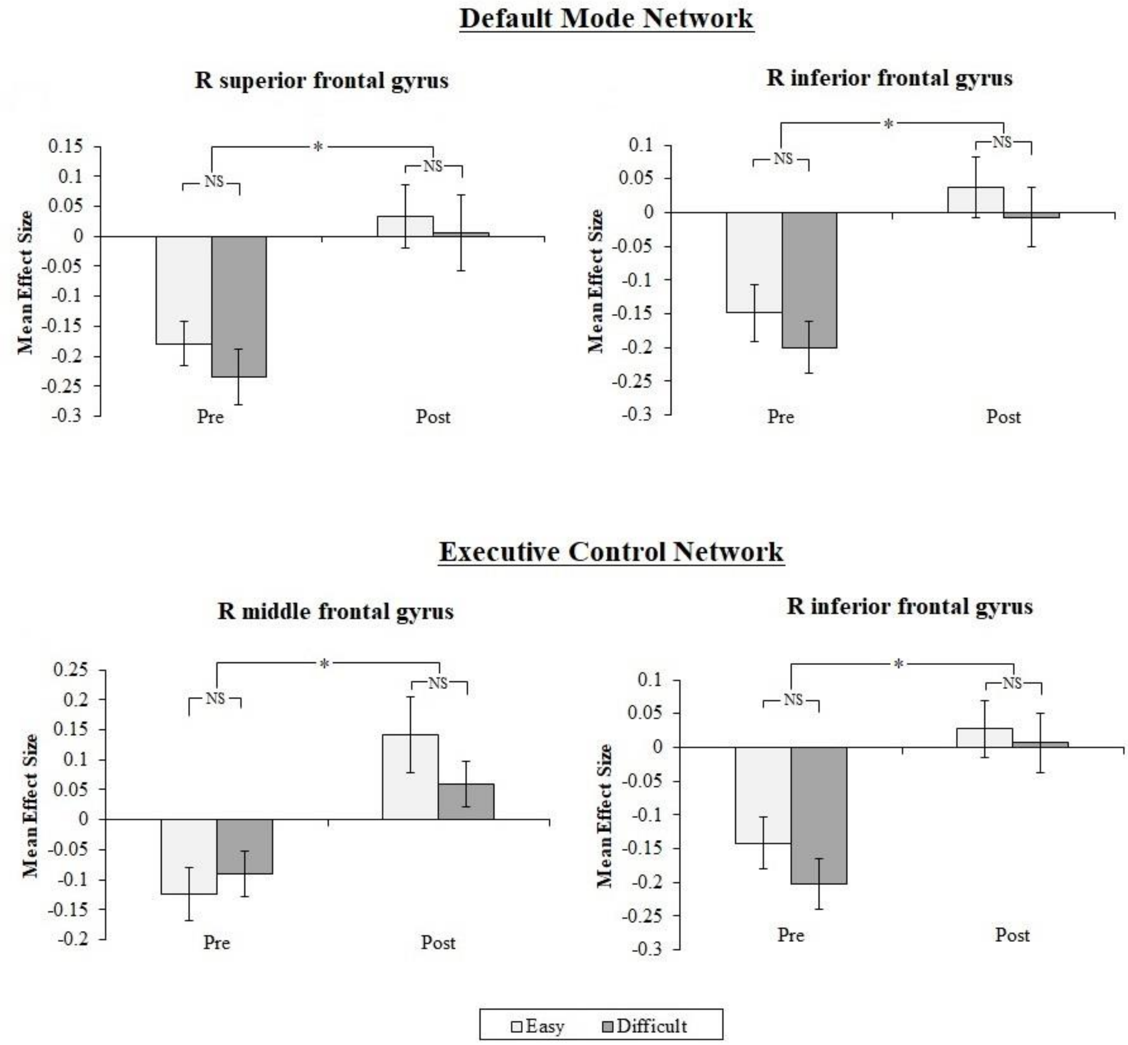

Figure E.1. BOLD contrast effect sizes (SPM beta weights) for significant clusters detected in the post>pre t-contrast when masking for the DMN and ECN, separated by inhibitory task condition. Error bars show ± 1 SEM. Note. * $p < .001$.

Appendix F: BOLD contrast effect sizes for significant clusters in whole brain post>pre analysis

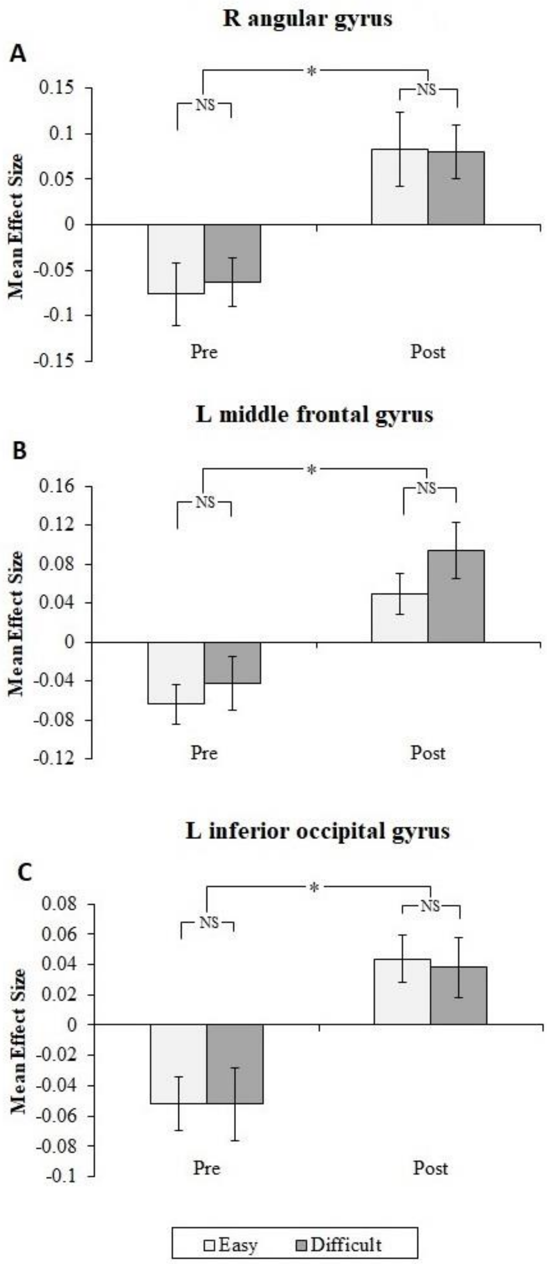

Figure F.1. BOLD contrast effect sizes (SPM beta weights) for significant clusters detected in the whole brain post>pre t-contrast (see corresponding A-C in Figure 6) separated by inhibitory task condition. Error bars show ± 1 SEM. Note. * $p < .001$.

Appendix G: Significant clusters for all t-contrasts

Table G.1. Significant FDR corrected clusters following height thresholding at *p*<.001 for all t-contrasts.

Region	Cluster *pFDR*	*K*	Peak *pFWE*	*Z*	x	y	z
Pre							
R Sub Gyral	.022	16	.044	4.46	30	35	5
R Superior Temporal Gyrus	.009	22	.079	4.34	46	-17	1
R Rolandic Operculum	.044	10	.103	4.28	42	-9	21
L Medial Frontal Gyrus	.035	12	.261	4.07	-18	39	21
R Sub Gyral	.044	10	.524	3.90	38	-49	33
Post							
R Sub Gyral	.010	19	.054	4.42	38	-49	21
R Superior Frontal Gyrus	<.001	69	.055	4.41	18	43	21
R Postcentral Gyrus	.042	12	.067	4.37	30	-29	45
R Superior Temporal Gyrus	.011	18	.089	4.31	58	7	-7
L Angular Gyrus	.002	28	.108	4.27	-38	-65	33
L Middle Frontal Gyrus	.015	16	.222	4.10	-42	19	41
R Middle Frontal Gyrus	.010	20	.280	4.05	34	15	41
Post>Pre							
R Superior Frontal Gyrus	.002	29	.040	4.48	22	31	45
R Angular Gyrus	.005	21	.146	4.20	42	-57	49
R Inferior Frontal Gyrus (pars triangularis)	.005	23	.176	4.16	54	27	17
R Middle Frontal Gyrus	.027	13	.529	3.90	42	7	37
L Middle Frontal Gyrus	.006	19	.626	3.86	-42	15	41
L Inferior Occipital Gyrus	.041	11	.713	3.79	-42	-9	-3
Difficult							

L Superior Medial Frontal Gyrus	.036	13	.072	4.36	-6	35	53
L Supramarginal Gyrus	<.001	50	.080	4.33	-54	-45	29
R Supramarginal Gyrus	.036	14	.111	4.26	42	-49	33
L Dorsolateral Superior Frontal Gyrus	.008	21	.516	3.90	-18	51	9