

The Neurophysiology of Emotion Regulation

**Glyn Paul Hallam**

**Thesis submitted in partial fulfillment for the degree of Doctor of Philosophy**

**The University of Sheffield**

**Academic Clinical Psychiatry, Department of Neuroscience**

**June 2013**

**Abstract**

The ability to adaptively control one’s own emotional experience, and interact with other people in order to influence their emotional state, is ubiquitous in all aspects of our daily functioning. The overarching aim of this thesis was to address a number of different questions concerning the neural basis of emotion regulation. The first research question was interested in examining the neural underpinnings of emotion regulation where the target of the regulation is another person (interpersonal emotion regulation) rather than the self (intrapersonal emotion regulation). This question was identified following a comprehensive review of the literature on the neural basis of emotion regulation, identifying the lack of research relating to interpersonal emotion regulation, even despite the prevalence of interpersonal emotion regulation in day-to-day life and its critical importance in interpersonal and social functioning. Chapter 2 therefore describes a novel fMRI task during which participants were required to interact with another person in order to achieve interpersonal emotion regulation (i.e. regulate the other person’s emotion). It was found that, when compared with a matched intrapersonal emotion regulation task, the process of interpersonal emotion regulation involved overlap with the neural substrates underlying the regulation of one’s own emotion, particularly within frontal cortex. However it was also found that interpersonal emotion regulation was underpinned by activation of areas known to be involved in aspects of social cognition such as mentalizing (e.g. anterior temporal pole, medial prefrontal cortex). This study therefore contributes to the knowledge of the neural basis of emotion regulation by showing that interpersonal emotion regulation relies upon facets of social cognition such as mentalizing in order to be successfully completed.

The second research question to be identified was to what extent ‘voluntary’ and ‘automatic’ emotion regulation processes overlap or differ in terms of their neural basis. Chapter 3 therefore describes an fMRI study that was designed to probe the neural correlates of a form of emotion regulation that might be considered more ‘automatic’ in its nature; one that is

supported by ‘implementation intentions’. Implementation intentions are ‘if-then’ plans that link a situational cue (e.g., “If I see something disgusting”) with a suitable goal-directed response (e.g., “then I will think these are just pixels on the screen!”). It was found that emotion regulation supported by implementation intentions was underpinned by activation within right inferior frontal gyrus (rIFG) and right ventro-parietal cortex (rVPC) and inferior parietal lobule (IPL), which may reflect the attentional control processes automatically captured by the cue for action. Direct comparisons between ‘voluntary’ emotion regulation (known as ‘goal intentions’) and implementation intentions also revealed that the modulation of activity within left amygdala was less effective for participants who formed only goal intentions to regulate (i.e., those who intended to regulate, but did not form a specific if-then plan to support this intention), supporting the increased efficacy of implementation intentions for emotion regulation, given that the amygdala is known to be involved in affective processing. The study described in chapter 3 is the first to use fMRI to investigate the neural basis of emotion regulation by implementation intentions and contributes to our understanding of the differing neural mechanisms underpinning effortful and automatic emotion regulation. The findings of chapter 3 also have translational clinical value given the high prevalence of emotion regulation deficits, particularly those of a more automatic nature, in psychiatric illness.

Chapter 4 describes an investigation into whether, based on the knowledge obtained from chapters 2 and 3 and from previous investigations into the neural basis of emotion regulation, the efficacy of emotion regulation can be modulated by application of transcranial direct current stimulation (tDCS) to the left dorsolateral prefrontal cortex (DLPFC). Such an investigation allowed for an exploration of the causal role of the DLPFC in emotion regulation. It was found that anodal (excitatory) stimulation increased the efficacy of emotion regulation when using one particular strategy for emotion regulation, cognitive reappraisal, as measured by both self report and physiological measures (skin conductance response). However there was no effect found for the same procedure when looking at a different emotion regulation strategy, expressive suppression. This study therefore makes an original contribution to the knowledge of the neural basis of emotion regulation by demonstrating that manipulating the activity of brain areas such as DLPFC can manifest in observable effects on an individual’s ability to regulate emotion by cognitive reappraisal, and also suggests that tDCS might have the potential to become an adjunct treatment for difficulties with emotion regulation.

Chapter 5 describes work that utilized the high-resolution structural MRI scans obtained from the participants who took part in the study described in chapter 3 to investigate the relationship between brain structure, specifically grey matter volume, and automatic emotion regulation. This took the form of a voxel-based morphometry (VBM) study, using a measure of tendency to engage in automatic emotion regulation as indexed by scores on the Emotion Regulation Implicit Association Test (ER-IAT; Mauss *et al*., 2006). It was found that those individuals with a greater tendency to engage in automatic emotion regulation displayed reduced grey matter volume within a region of dorsal anterior cingulate cortex, suggesting a role for dorsal anterior cingulate in emotion regulation in detecting the need for cognitive control.

Chapter 6 summarises the studies described within chapters 2, 3, 4 and 5, discusses the merits of the contribution of each study, and suggests avenues for further investigation. For example, future work is suggested that would expand the knowledge gained from chapter 2, suggesting that interpersonal emotion regulation critically relies on ‘intact’ social cognition, that would investigate how the nature of the relationship between the protagonists in an interpersonal emotion regulation interaction might result in different neural correlates. Further work to emerge from chapter 3, given the finding that attentional control networks underpinned the efficacy of emotion regulation by implementation intentions, might include further investigation into how the nature of the cue for action might affect the neural underpinnings. The finding in Chapter 4 that anodal tDCS was able to enhance the efficacy of emotion regulation has particular implications for potential treatment of emotion dysregulation, and several such avenues are discussed.

**List of abbreviations**

AAL – Automated anatomical labeling

ACC – Anterior cingulate cortex

ANOVA – Analysis of variance

BA – Brodmann area

BOLD – Blood oxygen level dependant

DLPFC – Dorsolateral prefrontal cortex

dmPFC – Dorso-medial prefrontal cortex

EEG – Electroencepholography

EPI – Echo planar imaging

ERQ – Emotion regulation questionnaire

ER-IAT – Emotion regulation implicit association test

fMRI – Functional magnetic resonance imaging

FOV – Field of view

FWE – Family wise error

IAPS – International affective picture system

IFG – Inferior frontal gyrus

IMMO – Implementation-maintenance model

IPL – Inferior parietal lobule

IRI – Interpersonal reactivity index

ISCR – Integrated skin conductance response

LFC – Lateral frontal cortex

MarsBaR - Marseille Boîte À Région d'Intérêt

MFG – Middle frontal gyrus

mPFC – medial prefrontal cortex

MP-RAGE - Magnetization-prepared rapid acquisition with gradient echo

MR – Magnetic resonance

MRI – Magnetic resonance imaging

OFC – Orbitofrontal cortex

PFC – Prefrontal cortex

PPI – Psychophysiological interaction

pSMA – Pre-supplementary motor area

SCR – Skin conductance response

SFG – Superior frontal gyrus

sgACC – Sub-genual anterior cingulate

SPM – Statistical parametric mapping

STS – Superior temporal sulcus

tDCS – Transcranial direct current stimulation

TE- Time to echo

TMS – Transcranial magnetic stimulation

TPJ – Temporo-parietal junction

TR – Time to repeat

VLPFC – Ventrolateral prefrontal cortex

vmPFC – Ventro-medial prefrontal cortex

VPC – Ventro-parietal cortex

WFU – Wake Forest University

3T – 3 Tesla

Table of Contents

[Acknowledgements 21](#_Toc370379140)

[Author’s Declaration 22](#_Toc370379141)

[Chapter 1- Emotion Regulation 24](#_Toc370379142)

[1.1 Overview 24](#_Toc370379143)

[1.1.2 What is an emotion? 24](#_Toc370379144)

[1.2 Emotion Regulation 25](#_Toc370379145)

[1.2.1 Why do we regulate our emotions? 25](#_Toc370379146)

[1.3 Consequences of emotion regulation strategies 29](#_Toc370379147)

[1.4 The neurophysiological basis of emotion regulation 30](#_Toc370379148)

[1.4.1 Brain areas involved in emotion regulation 31](#_Toc370379149)

[1.4.1.1 Dorsolateral prefrontal cortex (DLPFC) 31](#_Toc370379150)

[1.4.1.2 Orbitofrontal cortex 31](#_Toc370379151)

[1.4.1.3 Ventrolateral prefrontal cortex (VLPFC) 32](#_Toc370379152)

[1.4.1.4 Medial prefrontal cortex (mPFC) 32](#_Toc370379153)

[1.4.1.5 Amygdala 32](#_Toc370379154)

[1.4.1.6 Basal ganglia 32](#_Toc370379155)

[1.4.1.7 Insula 33](#_Toc370379156)

[1.4.1.8 Anterior Cingulate 33](#_Toc370379157)

[1.4.2 Functional Magnetic Resonance Imaging (fMRI) 34](#_Toc370379158)

[1.4.2.1 fMRI of emotion regulation 34](#_Toc370379159)

[1.4.3 Connectivity 38](#_Toc370379160)

[1.5 Types of reappraisal 39](#_Toc370379161)

[1.5.1 How does the type of emotion influence the neural basis of emotion regulation? 40](#_Toc370379162)

[1.6 Individual Differences 42](#_Toc370379163)

[1.6.1 The role of gender in emotion regulation 42](#_Toc370379164)

[1.6.2 Emotion Regulation in children 43](#_Toc370379165)

[1.6.3 Emotion Regulation in later adulthood 44](#_Toc370379166)

[1.6.4 Personality 45](#_Toc370379167)

[1.7 Ecologically valid emotion regulation 45](#_Toc370379168)

[1.8 Meta-analysis of emotion regulation 46](#_Toc370379169)

[1.8.1 Temporal aspects of emotion regulation 47](#_Toc370379170)

[1.8.2 What does each brain region do during reappraisal? 47](#_Toc370379171)

[1.9 Stimulus presentation 48](#_Toc370379172)

[1.10 Interpersonal Emotion Regulation 48](#_Toc370379173)

[1.11 Automaticity and emotion regulation 50](#_Toc370379174)

[1.11.1 Development of Automatic Emotion Regulation 51](#_Toc370379175)

[1.12 Modulation of emotion regulation 52](#_Toc370379176)

[Chapter 2 – the neural correlates of intrapersonal and interpersonal emotion regulation 54](#_Toc370379177)

[2.1 Differences between intrapersonal and interpersonal emotion regulation 57](#_Toc370379178)

[2.2 Stimulus development 58](#_Toc370379179)

[2.2.1 Methodology 58](#_Toc370379180)

[2.2.2 Paradigm development 59](#_Toc370379181)

[2.2.3 Regulation instructions: Manipulation of inter- versus intra-personal emotion regulation 62](#_Toc370379182)

[2.2.4 Regulation instructions: Manipulation of emotion regulation strategy 63](#_Toc370379183)

[2.2.5 Trial procedure 63](#_Toc370379184)

[2.2.6 Order of experimental runs 64](#_Toc370379185)

[2.3 Behavioural pilot 64](#_Toc370379186)

[2.3.1 Results of piloting 65](#_Toc370379187)

[2.3.2 Feasibility 65](#_Toc370379188)

[2.3.3 Intrapersonal – Felt Emotion 65](#_Toc370379189)

[2.3.4 Intrapersonal – Effort 65](#_Toc370379190)

[2.3.5 Intrapersonal – Difficulty 66](#_Toc370379191)

[2.3.6 Interpersonal – Other person’s Felt Emotion 66](#_Toc370379192)

[2.3.7 Interpersonal – Effort 67](#_Toc370379193)

[2.3.8 Interpersonal – Difficulty 67](#_Toc370379194)

[2.3.9 Changes to fMRI paradigm following piloting 67](#_Toc370379195)

[2.3.10 Authenticity of video link 68](#_Toc370379196)

[2.4 fMRI study 68](#_Toc370379197)

[2.4.1 Hypotheses 68](#_Toc370379198)

[2.5 Materials and Methods 69](#_Toc370379199)

[2.5.1 Participants 69](#_Toc370379200)

[2.5.2 Pre-scan session 70](#_Toc370379201)

[2.6 Design and Stimuli 72](#_Toc370379202)

[2.6.1 fMRI data acquisition 73](#_Toc370379203)

[2.6.2 fMRI data preprocessing 73](#_Toc370379204)

[2.7 Results 74](#_Toc370379205)

[2.7.1 Effect of intrapersonal and interpersonal emotion regulation on self-report behavioural ratings 74](#_Toc370379206)

[2.7.2 fMRI results - Common neurophysiological bases of intrapersonal and interpersonal emotion regulation 75](#_Toc370379207)

[2.7.3 Neurophysiological basis of intrapersonal and interpersonal emotion regulation 76](#_Toc370379208)

[2.7.4 Comparison of the neurophysiological bases of intrapersonal and interpersonal emotion regulation 79](#_Toc370379209)

[2.7.5 Interpersonal reappraisal 83](#_Toc370379210)

[2.7.6 Interpersonal suppression 83](#_Toc370379211)

[2.7.7 Post scan debriefing 84](#_Toc370379212)

[2.8 Discussion 87](#_Toc370379213)

[2.8.1 Imaging data 87](#_Toc370379214)

[2.8.2 The neurophysiology of interpersonal emotion regulation 90](#_Toc370379215)

[2.8.3 Limitations 91](#_Toc370379216)

[2.8.4 Clinical Implications 93](#_Toc370379217)

[2.9 Conclusion 94](#_Toc370379218)

[Chapter 3 – the neurophysiology of intrapersonal emotion regulation by implementation intentions 95](#_Toc370379219)

[3.1 Implementation intentions 95](#_Toc370379220)

[3.1.2 Implementation intentions and automaticity 96](#_Toc370379221)

[3.1.3 Implementation intentions and emotion regulation 96](#_Toc370379222)

[3.1.4 Goal intentions 97](#_Toc370379223)

[3.1.5 Neural basis of automatic emotion regulation 98](#_Toc370379224)

[3.1.6 Hypotheses 99](#_Toc370379225)

[3.2 Scanning paradigm 100](#_Toc370379226)

[3.2.1 Stimuli 100](#_Toc370379227)

[3.2.2 Paradigm details 102](#_Toc370379228)

[3.2.3 Instructions 103](#_Toc370379229)

[3.2.4 Implementation intentions v goal intentions 105](#_Toc370379230)

[3.2.5. Feasibility of within subjects design 105](#_Toc370379231)

[3.3 fMRI study 106](#_Toc370379232)

[3.3.1 Participants 106](#_Toc370379233)

[3.3.2 Procedure 106](#_Toc370379234)

[3.3.3 Pre-scan session 106](#_Toc370379235)

[3.3.4 Paradigm 107](#_Toc370379236)

[3.3.5 fMRI data acquisition 108](#_Toc370379237)

[3.3.6 Stimulus presentation 108](#_Toc370379238)

[3.3.7 fMRI data preprocessing 108](#_Toc370379239)

[3.3.8 Conventional analyses 108](#_Toc370379240)

[3.3.9 Connectivity analyses 109](#_Toc370379241)

[3.4 Skin Conductance Response 110](#_Toc370379242)

[3.5 Results 111](#_Toc370379243)

[3.5.1 Baseline characteristics of participants 111](#_Toc370379244)

[3.5.2 Behavioural results 111](#_Toc370379245)

[3.5.3 Neuroimaging data 113](#_Toc370379246)

[3.5.4 Implementation intentions 113](#_Toc370379247)

[3.5.6 Goal intentions 115](#_Toc370379248)

[3.5.7 Goal intentions > Implementation intentions 115](#_Toc370379249)

[3.5.8 Implementation intentions > goal intentions 116](#_Toc370379250)

[3.5.9 Correlation with behavioural data 118](#_Toc370379251)

[3.6 Connectivity analyses 119](#_Toc370379252)

[3.6.1 Goal intentions 119](#_Toc370379253)

[3.6.2 Implementation intentions 119](#_Toc370379254)

[3.6.3 Goal intentions > implementation intentions 120](#_Toc370379255)

[3.6.4 Implementation intentions > goal intentions 120](#_Toc370379256)

[3.7 Skin Conductance Response 120](#_Toc370379257)

[3.8 Discussion 122](#_Toc370379258)

[3.8.1 Limitations 127](#_Toc370379259)

[3.8.2 Clinical Relevance 127](#_Toc370379260)

[3.9 Conclusion 128](#_Toc370379261)

[Chapter 4 – The modulation of intrapersonal emotion regulation by Transcranial Direct Current Stimulation (tDCS) 129](#_Toc370379262)

[4.1 Transcranial Direct Current Stimulation (tDCS) 129](#_Toc370379263)

[4.1.1 Pharmacological effects of tDCS 132](#_Toc370379264)

[4.1.2 Effects of tDCS on haemodynamics 132](#_Toc370379265)

[4.1.3 Effect of electrode size 133](#_Toc370379266)

[4.1.4 Electrode montage 133](#_Toc370379267)

[4.2 tDCS and emotion processing 134](#_Toc370379268)

[4.2.1 tDCS and the DLPFC 134](#_Toc370379269)

[4.3 tDCS and emotion regulation 135](#_Toc370379270)

[4.4 tDCS and clinical disorders 136](#_Toc370379271)

[4.5 Experimental design 137](#_Toc370379272)

[4.5.1 Study 1. 137](#_Toc370379273)

[4.5.2 Study 1 participants 138](#_Toc370379274)

[4.5.3 Neuropsychological measures 139](#_Toc370379275)

[4.5.4 Study 2 139](#_Toc370379276)

[4.5.5 Study 2 Participants 140](#_Toc370379277)

[4.6 Stimuli 140](#_Toc370379278)

[4.6.1 Paradigm 143](#_Toc370379279)

[4.6.2 SCR data collection 144](#_Toc370379280)

[4.7 SCR Data processing 144](#_Toc370379281)

[4.8 Behavioural data 144](#_Toc370379282)

[4.9 Results 145](#_Toc370379283)

[4.9.1 Baseline characteristics 145](#_Toc370379284)

[4.9.2 Affect ratings 146](#_Toc370379285)

[4.9.3 Difficulty ratings 147](#_Toc370379286)

[4.9.4 Effect of tDCS on self-reported affect ratings 149](#_Toc370379287)

[4.9.6 Effect of tDCS on self reported affect ratings for study 1 (reappraisal) 150](#_Toc370379288)

[4.9.8 Effect of tDCS on self reported affect ratings for study 2 (suppression) 151](#_Toc370379289)

[4.10 Skin conductance response data 152](#_Toc370379290)

[4.10.1 Interaction of tDCS stimulation with ISCR 152](#_Toc370379291)

[4.10.4 Correlation of neuropsychological measures with task performance 154](#_Toc370379292)

[4.11 Discussion 155](#_Toc370379293)

[4.11.1 Overall effect of emotion regulation 156](#_Toc370379294)

[4.11.2 tDCS and self report measures 157](#_Toc370379295)

[4.11.3 Effect of tDCS on SCR 159](#_Toc370379296)

[4.12 Limitations 159](#_Toc370379297)

[4.12.2 Further studies 160](#_Toc370379298)

[4.13 Clinical applications 161](#_Toc370379299)

[4.14 Conclusion 161](#_Toc370379300)

[Chapter 5 – Structural correlates of emotion regulation 163](#_Toc370379301)

[5.1 Voxel-based morphometry (VBM) 163](#_Toc370379302)

[5.2 VBM studies of emotion regulation 164](#_Toc370379303)

[5.3 ER-IAT 165](#_Toc370379304)

[5.4 Hypotheses 165](#_Toc370379305)

[5.5 Materials and Methods 167](#_Toc370379306)

[5.5.1 Participants 167](#_Toc370379307)

[5.5.2 Behavioural measures 167](#_Toc370379308)

[5.5.3.1 ER-IAT 167](#_Toc370379309)

[5.5.3.2 Personality Inventory 168](#_Toc370379310)

[5.6 MRI data acquisition 168](#_Toc370379311)

[5.7 Data Analysis 168](#_Toc370379312)

[5.7.1 ER-IAT 168](#_Toc370379313)

[5.7.2 VBM 169](#_Toc370379314)

[5.8 Results 169](#_Toc370379315)

[5.8.1 Personality inventory 169](#_Toc370379316)

[5.8.2 ER-IAT 170](#_Toc370379317)

[5.8.3 VBM 170](#_Toc370379318)

[5.9 Discussion 171](#_Toc370379319)

[5.10 Limitations 173](#_Toc370379320)

[5.11 Conclusion 174](#_Toc370379321)

[Chapter 6 - General Discussion 175](#_Toc370379322)

[6.1 How has the thesis advanced understanding of the neural basis of emotion regulation? 176](#_Toc370379323)

[6.1.1 The neural basis of interpersonal emotion regulation 176](#_Toc370379324)

[6.1.2 The neural basis of automatic emotion regulation 177](#_Toc370379325)

[6.1.3 The modulation of emotion regulation by brain stimulation 179](#_Toc370379326)

[6.1.4 Structural correlates of automatic emotion regulation 180](#_Toc370379327)

[6.1.5 Structural and Functional correlates of automatic emotion regulation 180](#_Toc370379328)

[6.2 Methodological contributions of thesis 182](#_Toc370379329)

[6.3 Future directions 183](#_Toc370379330)

[6.4 Emotion regulation and psychiatric illness 184](#_Toc370379331)

[6.4.1 Previous work on the neural basis of emotion regulation in psychiatric illness 185](#_Toc370379332)

[6.5 Limitations of the thesis and future directions 188](#_Toc370379333)

[6.6 Conclusions 191](#_Toc370379334)

[7.0 References 192](#_Toc370379335)

[Appendices 213](#_Toc370379336)

[Appendix 1 – Ethical approval for the studies 213](#_Toc370379337)

[Appendix 2 – Consent form for fMRI studies 214](#_Toc370379338)

[Appendix 3 – tDCS consent form 216](#_Toc370379339)

[Appendix 4 – Description of video clips used in chapter 2 218](#_Toc370379340)

[Appendix 5 – IAPS images used in chapter 3 220](#_Toc370379341)

[Appendix 6 – Disgust Sensitivty Scale revised 221](#_Toc370379342)

[Appendix 7 – PANAS-X 223](#_Toc370379343)

[Appendix 8 226](#_Toc370379344)

**List of tables (by chapter)**

**Chapter 2**

[Table 2.1 Areas activated in both tasks (intrapersonal regulation – watch, interpersonal regulation – watch 76](#_Toc359941576)

[Table 2.2. Areas activated in the contrast intrapersonal emotion regulation (reappraisal and suppression combined) > watch 77](#_Toc359941577)

[Table 2.3. Areas activated in the contrast interpersonal emotion regulation (reappraisal and suppression combined) > watch 78](#_Toc359941578)

[Table 2.4 – Areas activated by the main effect of intrapersonal emotion regulation (intrapersonal emotion regulation – watch > interpersonal emotion regulation > watch) 80](#_Toc359941579)

[Table 2.5 – Areas activated by the main effect of interpersonal emotion regulation (interpersonal emotion regulation – watch > intrapersonal emotion regulation > watch) 82](#_Toc359941580)

[Table 2.6 – Areas activated by interpersonal emotion regulation 84](#_Toc359941581)

**Chapter 3**

[Table 3.1. Participants in the goal and implementation intentions groups 111](#_Toc359941582)

[Table 3.2 – Brain areas activation by implementation intentions 113](#_Toc359941583)

[Table 3.3. Areas activated in the contrast goal intentions > attend (includes only participants who received goal intention instructions). 115](#_Toc359941584)

[Table 3.4. Areas activated in the contrast implementation intentions (> attend) > goal intentions (>attend). 117](#_Toc359941585)

[Table 3.5. Areas demonstrating enhanced connectivity with the left amygdala under the condition of emotion regulation by goal intention than under attend (includes only participants who received goal intention instructions). 121](#_Toc359941586)

[Table 3.6. Areas demonstrating enhanced connectivity with the left amygdala under the condition of emotion regulation by implementation intention than under attend 122](#_Toc359941587)

**Chapter 4**

[Table 4.1 – baseline characteristics of participants 145](#_Toc359941588)

**List of figures (by chapter)**

**Chapter 1**

[Figure 1.1: Gross’s Process Model of Emotion Regulation 28](#_Toc369776332)

**Chapter 2**

[Figure 2.1 – Screen shots from the videos of the other person 61](#_Toc369776333)

[Figure 2.2 - Description of paradigm 71](#_Toc369776334)

[Figure 2.3 - Mean self report affect rating 75](#_Toc369776335)

[Figure 2.4 - Intrapersonal regulation > interpersonal regulation 80](#_Toc369776336)

[Figure 2.5 – Interpersonal regulation > Intrapersonal regulation 82](#_Toc369776337)

**Chapter 3**

[Figure 3.1 – Events comprising each trial 108](#_Toc369776338)

[Figure 3.2 - Mean change in affect ratings as a function of emotion regulation for the two groups. 112](#_Toc369776339)

[3.5.5 Differences between reappraisal and suppression implementation intention strategies 114](#_Toc369776340)

[Figure 3.3 – Brain areas more involved in emotion regulation by implementation intentions 116](#_Toc369776341)

[Figure 3.5 – Correlation between the reduction in amygdala signal as a function of emotion regulation and the reduction in self report affect rating as a function of emotion regulation 119](#_Toc369776342)

**Chapter 4**

[Figure 4.1 – tDCS equipment. 130](#_Toc369776343)

[Figure 4.2: EEG 10-20 International System 141](#_Toc369776344)

[Figure 4.3. Mean affect ratings in the “watch” condition (blue) and “reappraise” condition (green) 146](#_Toc369776345)

[Figure 4.4: Mean affect ratings and confidence intervals in the “watch” condition (blue) and “suppress” condition (red). 147](#_Toc369776346)

[Figure 4.5: Mean difficulty ratings and confidence intervals in the “watch” condition (blue) and “reappraise” condition (green). 148](#_Toc369776347)

[Figure 4.6: Mean difficulty ratings and confidence intervals in the “watch” condition (blue) and “suppress” condition (red 149](#_Toc369776348)

[Figure 4.7. Affect rating in response to disgusting videos 150](#_Toc369776349)

[Figure 4.8. Affect rating for study 2 (suppression). 151](#_Toc369776350)

[Figure 4.9: Mean ISCR by stimulation and regulation type 154](#_Toc369776351)

[Figure 4.10: Significant positive correlation between average Disgust Scale-Revised score and mean affect rating in response to disgusting videos 155](#_Toc369776352)

**Chapter 5**

[Figure 5.1 – Brain areas demonstrating differences in grey matter thickness as a function of score on the ER-IAT. 171](#_Toc369776353)

# Acknowledgements

I wholeheartedly thank my supervisors Dr. Tom Farrow and Dr. Tom Webb for their invaluable guidance and support. I also thank all members of the Sheffield Cognition and Neuroimaging Laboratory (SCANLab) and all members of Academic Clinical Psychiatry.

I thank the ESRC for their funding that supported the studies described in chapters 2,3 and 5 of this thesis. I thank other members of the same research network (EROS; Emotion Regulation of Others and the Self) for their comments and guidance, particularly Prof. Peter Totterdell, Prof. Paschal Sheeran, Dr. Eleanor Miles, and Dr. Karen Niven.

I am grateful to the skills of Prof. Iain Wilkinson and colleagues in the Department of Academic Radiology, and particularly to the radiographers. Many thanks also to Prof. Tony Barker who manufactured the tDCS and SCR kit used in these studies.

Finally Rachael, the most patient and supportive person I am ever likely to know.

# Author’s Declaration

I declare that the work in this dissertation was carried out in accordance with the Regulations of the University of Sheffield. The experiments described by the author are original and were carried out under the supervision of Dr. Tom Farrow and Dr. Thomas Webb at the University of Sheffield. The work was funded by the Economic and Social Research Council (grant number RES-060-25-0044). Any views expressed in this thesis are those of the author and in no way represent those of the University of Sheffield.

This research has not been previously submitted to the University of Sheffield or to any other University for examination. Part of the data collection from experiment described in Chapter 4 was carried out by Isabelle Van Heejswijk as part of her BMedSci project (that was co-supervised by the author). However, analyses for the final data sets reported here were conducted independently.

The ER-IAT data described in chapter 5 were originally collected in order to provide additional data for another study, which is not described in this thesis. All data collection for this study was performed by the author. Data analysis for the ER-IAT was performed by the author, using SPSS syntax written by Dr. Eleanor Miles from the Department of Psychology.

All other data collection, paradigm design, and data analysis was carried out by the author.

The data from chapter 2 have been presented as a poster:

Hallam, G.P., Webb, T.L., Sheeran, P., Miles, E., Wilkinson, I.D., Woodruff, P.W.R., Totterdell, P., & Farrow, T.F.D. (2010, June). Neuroimaging of Self and Other Emotion Regulation. 16th Annual Meeting of the Organization for Human Brain Mapping, Barcelona, Spain.

The data reported in chapter 2 have also previously been submitted for review at *Neuropsychologia* (The neural correlates of regulating another person’s emotion).

The data from chapter 3 have been presented as a poster:

Hallam, G.P., Webb, T.L., Sheeran, P., Wilkinson, I.D., Totterdell, P, Hunter, M., Woodruff, P.W.R, & Farrow, T.F.D. (2012, June). The neural basis of emotion regulation supported by implementation intentions. 18th Annual Meeting of the Organization for Human Brain Mapping, Beijing, China.

The data reported in chapter 3 are also currently under review at *NeuroImage* (The neural basis of implementation intentions for emotion regulation).

The data reported in Chapter 4 and 5 are currently in preparation for submission to *NeuroImage* (Chapter 5) and *PLoS1* (Chapter 4).

**Overview of thesis**

This thesis is presented so that each chapter comprises a self-contained study, given the varied nature of the research questions the thesis aimed to address. Within each chapter, the background to each study is further outlined, and the relevant literature discussed. Chapter 1 of the thesis provides a review of the previous literature on which the current series of studies was built. Chapter 6 provides further discussion of each of the three studies, discusses the overlapping themes to emerge from them in the broader context of the existing literature, and provides an assessment of the general contributions of the thesis.

# Chapter 1- Emotion Regulation

## 1.1 Overview

**This chapter comprises a review of the previous literature on which the current series of studies was built. This covers the concept of emotion and emotion regulation; what it is, why it occurs, and how it occurs. Different strategies for emotion regulation will be discussed, with particular emphasis on cognitive reappraisal and expressive suppression. Research concerning the neurophysiological underpinnings of emotion regulation using such strategies is then explored. The concepts of intrapersonal (regulating one’s own emotion) and interpersonal emotion regulation (regulating another person’s emotion) are also discussed, with the emphasis drawn on the paucity of research investigating the neural basis of interpersonal emotion regulation. The chapter will also introduce the other aims of the thesis that are identified from a number of outstanding research questions. This includes the differences between effortful and automatic forms of emotion regulation, and whether brain stimulation can be used to alter emotion regulation and the way in which it is implemented.**

### 1.1.2 What is an emotion?

Any series of investigations into the nature of emotion regulation would clearly benefit from a working definition of what is ‘emotion’ in itself. A variety of (often interchangeable) definitions describing ‘emotion’ have been used throughout the literature, particularly within the field of affective neuroscience. Terms such as ‘emotion’, ‘affect’, ‘mood’, and ‘feeling state’ all commonly appear, often referring to ostensibly the same concepts (Izard, 2010). Emotions, in a similar fashion to ‘mood’ or ‘affect’, can be defined as valenced affective responses; they can be negative (e.g. sadness, anger, and disgust) or positive (e.g. joy, happiness). However a key difference between emotion and ‘mood’ is that emotions have precise “triggers” for their onset, and tend to be of a far shorter duration (Beedie, Terry & Lane, 2005). Emotions can also be further differentiated from ‘moods’ in that they trigger the requirement for behaviour in the individual, including the possibility of acting in such a way that changes the emotional state of the individual.

In simple terms, an emotion might be conceptualised as the set of processes (physiological, experiential and behavioural) that are triggered when a stimulus is appraised as being goal-relevant (Gross and Thompson, 2007). This definition is therefore one that will be used for the purposes of the studies described throughout the thesis.

## 1.2 Emotion Regulation

### 1.2.1 Why do we regulate our emotions?

The drive to change one’s emotional state can be described as a process of ‘emotion regulation’. Gross and Thompson (2007) define emotion regulation as the set of “automatic and controlled processes involved in initiation, maintenance, intensity and duration of feeling states”. Emotion regulation particularly acts on emotions that cause an undesirable mental state (whether that is positive or negative) or are incongruent with the current desires or goals of the individual. An example of this might be the need to regulate anxiety before a job interview, which if left unregulated would interfere with the individual’s ability to perform well in the interview. Or in the case of positive emotion, an example might be inhibiting a smile when a boss says something unintentionally amusing during an important meeting, but to which displaying signs of amusement, such as smiling or laughing, would be contextually inappropriate. Emotion regulation does not therefore occur simply in an attempt to ‘make yourself feel better’ (though this is often one of the primary reasons for regulating emotion). Emotion regulation can instead be seen as a set of strategies that an individual uses in an attempt to successfully negotiate their way in the world, by appropriately regulating their behaviour in relation to themselves and to other people.

Emotion regulation influences the type of emotion that an individual experiences (e.g. positive or negative), in addition to the timing of when that emotion arises, and the experiential, physiological and behavioural consequences (Gross, 1998). Emotion regulation can act on positive and negative emotional experience, and can refer to the up-regulation (i.e. increasing the intensity of the emotion), down-regulation (i.e. decreasing the intensity of the emotion), or maintenance of the current state (Parrott, 1993). The regulation of emotional states occurs on a daily basis in all individuals and is considered a vital component of the successful social functioning of an individual (Gross & John, 2003). There are also tangible beneficial physiological effects to appropriate regulation of emotion; for example one particular strategy for regulating emotion that will be discussed throughout the thesis, cognitive reappraisal, has been shown to be associated with improved immunological functioning, as measured by levels of saliva secretory immunoglobulin A (Zhang *et al.,* 2012).

Due to the constant need in daily life for individuals to engage in emotion regulation there are a considerable number of emotion regulation strategies that an individual might employ in order to change their emotional state. In one attempt to categorize the many different emotion regulatory strategies along the dimensions of when they occur and what effects they have, Gross (1998; 2002) developed a ‘process model’ of emotion regulation (Figure 1.1). This model categorizes different emotion regulation strategies according to at what temporal stage along the course of an emotion unfolding they occur. The model broadly splits the strategies into five categories in order of when they occur: situation selection, situation modification, attentional deployment, cognitive reappraisal (‘antecedent’ focused strategies) and expressive suppression (a ‘response’ focused strategy). Antecedent-focused strategies, encompassing the first four categories, are implemented and exert their effects either before the onset, or before full manifestation, of the emotional response. Response-focused regulation (i.e. expressive suppression) on the other hand occurs only (or at least only exerts its effects) after the full manifestation of an emotional response. The five different categories of the model are now briefly outlined:

*Situation selection* refers to the environmental choice an individual makes to either seek out or avoid a particular situation in which the individuals thinks, perhaps based on past experience, that an undesirable emotional state may be elicited. For example, this might involve choosing to sit at a desk in an office that is on the opposite side of the room from where loud building works are occurring just outside (that may elicit feelings of anger if it interferes with the person’s concentration).

*Situation modification* refers to behavioural processes that an individual might immediately take to modify their environment to deal with a potentially emotion eliciting stimulus if they have been unable to engage in *situation selection*, for example closing the office window to mask out the building noise before it gets to such a level that the individual becomes angry because of the noise.

The third stage of the model, *attentional deployment*, describes strategies that move from behavioural actions to more cognitive actions, whereby the individual redeploys their attentional resources to other aspects of their environment which are less likely to elicit an undesirable emotional state. An example of this might be choosing to focus on listening to the radio next to the individual’s desk rather than the background building noise. Such strategies could also be considered to constitute a form of *distraction*.

The final antecedent-focused strategy of *cognitive reappraisal* involves the cognitive reframing of a situation in order to change the way that an individual feels in response to it; essentially applying an alternative meaning or interpretation to a situation. For example this might involve the individual reframing the situation that although the loud building noise might ordinarily cause feelings of anger due to its intrusive nature, it will ultimately mean that the building is a more pleasant and productive place once the work has been finished.

Finally, r*esponse modulation* refers to response-focused strategies that are aimed at reducing the emotional state by acting on the emotion response components. The most common form of response modulation, expressive suppression, refers to the behavioural suppression of the overt signs of emotional state, primarily facial expression (though this may perhaps include other aspects of body posture, such as the way in which one stands). Essentially this involves not letting other people know about the emotional state that an individual is currently experiencing. For example, this might involve the individual ‘keeping a straight face’ despite feeling angry about the building noise, so that his colleagues would not know by looking at him that the noise is causing him to be angry.

*C:\Documents and Settings\ghallam\My Documents\Dropbox\PhD\PhD chapters\Final draft\New_figure_1.tif*

Figure 1.1: Gross’s Process Model of Emotion Regulation (adapted from Gross, 2002). This identifies a number of different stages at which emotion regulation interventions may occur, and which components they impact upon, whether it be the situation itself (situation selection, situation modification), aspects of the situation (attentional deployment), meanings of the situation (cognitive change) or aspects of the response itself (response modulation)

The strategies that comprise the five different stages of the model can therefore be said to exert their regulatory effect on different components of the emotional experience (Mauss, Bunge & Gross*,* 2007). For example, cognitive reappraisal is focused primarily on the experiential component of emotion (with a subsequent effect on the behavioural and physiological components), whereas expressive suppression is more focused on the behavioural component (i.e. not behaving in accordance with the current emotional state), but does not necessarily impact upon the physiological or experiential components.

Despite these discrete categorizations made for the different strategies, it is clear that there exists a degree of overlap between the strategies; for example cognitive reappraisal might be used to reframe a situation only after the initial emotional response has fully arisen, in situations where it might not always be possible to regulate the emotional response before its manifestation. However as a general framework the model has become widely used as the basis for a number of studies investigating the behavioural and physiological effects (Dan-Glauser & Gross, 2011) and neural basis of emotion regulation (e.g. Goldin *et al.,* 2008).

## 1.3 Consequences of emotion regulation strategies

Due to the fact that the different strategies have this effect on different components of the emotional response, cognitive reappraisal and expressive suppression have been shown to have different consequences to the individual. Reappraisal has traditionally been regarded as the more functional strategy, in comparison to suppression, in terms of favourable life outcomes such as well-being and interpersonal functioning (Gross & John, 2003). This might be related to the fact that in reappraisal an active attempt is made to engage with or reflect on the interpretation of the emotion-eliciting event, to such an extent that all aspects of the emotional response (experiential, behavioural and physiological) are reconciled. Suppression, on the other hand, does not necessarily reconcile all of these processes.

In one study investigating emotion regulation in patients with an anxiety or mood disorder, attempting to use expressive suppression during an emotional film was associated with increased heart rate compared to an ‘acceptance’ group (i.e. no emotion regulation), and equivalent increases in skin conductance and respiratory sinus arrhythmia (Campbell-Sills *et al.,* 2006). Regulation of emotion also modulates subsequent startle responses, skin conductance response and heart rate in line with the arousal rather than valence of stimuli (Dillon & Labar, 2005; Driscoll *et al.,* 2009). However it is also worth noting that there are differences in terms of autonomic arousal depending on whether regulation is ‘pre-cued’ or arises after the onset of an emotion-eliciting event. For example, Sheppes, Catran, & Meiran (2009) found that when reappraisal was only implemented after the onset of a sad emotional response (i.e. when reappraisal was not necessarily antecedent-focused), this was associated with increased sympathetic activation, as indexed by skin conductance response. This therefore suggests that reappraisal may not always be the most adaptive strategy in every situation (and suppression may not always be the most maladaptive strategy), and may relate to the fact that reappraisal is not always exclusively an antecedent-focused strategy.

Research has suggested that cognitive reappraisal is more likely to be spontaneously used than suppression for down-regulating negative emotion (Volokhov & Demaree, 2010). However this is not necessarily reflected in self-report psychometric measures (e.g. Emotion Regulation Questionnaire; Gross & John, 2003) which attempt to quantify the extent to which an individual typically uses reappraisal and suppression in real-world situations. One proposed reason for this is that reappraisal is critically underpinned by a salient context in which the emotion-eliciting situation can be reinterpreted. In support of this proposal, Feinstein, Duff & Tranel (2010) found that amnesic patients, after viewing sadness or happiness inducing video clips, had a subsequent longer persistence of either negative or positive emotion than control subjects. This might be interpreted as an inability to reappraise the negative feelings due to a loss of memory for their source (anecdotal evidence from individual participants cited in the paper lends support to this notion).

A recent meta-analysis (Webb, Miles & Sheeran, 2012) investigated the effectiveness of the different strategies identified by the process model, by extracting the outcome measures from a number of studies that investigated the control of emotion by each strategy (attentional deployment, cognitive change and response modulation). The meta-analysis found that cognitive change was associated with the largest improvements in outcomes (an effect size of d+ = 0.36), with response modulation resulting in smaller improvements (d+ = 0.16), therefore suggesting that different emotion regulation strategies in the process model are differential in their effectiveness.

## 1.4 The neurophysiological basis of emotion regulation

A number of different methods have proven useful in informing our understanding of the neural basis of emotion regulation. One of the first methods has been neuropsychological investigations of patients with lesions and brain injuries. The now famous case of Phineas Gage (Harlow, republished in 1993), who following severe damage to his vmPFC exhibited many problems with inhibition of behaviour and emotion, was influential in identifying a crucial role for the frontal cortex in the inhibition of behaviour.

Modern neuroimaging techniques such as functional magnetic resonance imaging (fMRI) have the potential to inform us in a more specific manner how different strategies for emotion regulation might be underpinned by particular networks in the brain, and interactions between different brain areas. This therefore offers an advantage over case studies of brain injured patients that have inherent limitations in their explanatory power due to the unique nature of each individual case, and the often widespread nature of the brain damage which makes drawing inferences about any one specific area of the brain problematic.

## 1.4.1 Brain areas involved in emotion regulation

There are several areas of the brain that, as the chapter will go on to explain, have been identified either by neuropsychological or neuroimaging investigations as being critically involved in underpinning emotion regulation. The reasons for the involvement of these particular brain areas will now be briefly explained.

### 1.4.1.1 Dorsolateral prefrontal cortex (DLPFC)

The DLPFC (comprising Brodmann Area 8/9/46) is known to be involved in a number of executive functions primarily related to working memory (Rowe *et al.,* 2000, Curtis & D’Esposito, 2003, Barbey, Koenings & Grafman, 2012). The involvement of DLPFC in emotion regulation might therefore be due to its role in working memory; in this sense, working memory might be considered an intrinsic component of emotion regulation.

### 1.4.1.2 Orbitofrontal cortex

The orbitofrontal cortex (comprising BA11) is intimately involved in decision making and tracking the value of rewards (Symmonds, Bossaerts & Dolan, 2010; Daw *et al.,* 2006; Kringelbach, 2005, Elliot, Dolan & Frith, 2000). The potential for its role in emotion regulation is therefore clear, due to the fact that emotion regulation involves both of these processes.

### 1.4.1.3 Ventrolateral prefrontal cortex (VLPFC)

The VLPFC (comprising BA44, 45, 47) is also involved in a number of executive functions. This includes attentional control and inhibition of motor responses (Levy & Wagner, 2011) as well as detection of salient cues (Hampshire *et al.,* 2010). The VLPFC has also been shown to have a role in deception (Spence e*t al.,* 2008) in relation to the withholding of a prepotent response. There has also been a role identified for the left VLPFC in working memory, relating to retrieval of previously stored information (Badre & Wagner, 2007).

### 1.4.1.4 Medial prefrontal cortex (mPFC)

The mPFC (BA8, 9, 10) covers a wide portion of frontal cortex and incorporates dorsal mPFC (BA8) and ventral mPFC (BA9/10). The mPFC, particularly BA 9 (superior frontal gyrus) has been associated with the process of mentalizing; that is attributing intentions and mental states to other people (Gallagher *et al.,* 2000, Vogeley *et al.,* 2001, Amodio & Frith, 2006).

### 1.4.1.5 Amygdala

The amygdala is a bilateral set of nuclei located deep in the temporal lobe and has particular involvement in the processing and representation of emotional experience, is particularly involved in the process of threat-related stimuli (Phan *et al*., 2002) as well as more general social cognition processes such as face processing and interpersonal functioning (Adolphs, 2010, Kennedy *et al.*, 2009).

### 1.4.1.6 Basal ganglia

The basal ganglia (particularly ventral striatum) are another set of subcortical nuclei that have been implicated in the anticipation of reward, learning (O’Doherty *et al.,* 2004), and avoidance behaviour (Levita, Hoskin & Champi, 2012). Emotional experience and regulation involves aspects of all of these behaviours and therefore the basal ganglia have been associated with both emotional experience (Phan *et al.*, 2002) and emotion regulation (van Reekum *et al.*, 2007).

### 1.4.1.7 Insula

The insula, located bilaterally, is involved in a wide variety of functioning but is particularly implicated in the processing and coordination of internal bodily states, and visceral sensation (Craig, 2009). This therefore means that it is one of the most commonly implicated structures in the experience of emotion.

### 1.4.1.8 Anterior Cingulate

The anterior cingulate cortex (ACC) is involved in a large number of cognitive processes. The common feature that seems to bind these functions together is that they contain an element of conflict monitoring, or detection of error. It has been proposed that the ACC could be considered part of the brain’s ‘alarm’ system that signals the need for effortful control when a change in the environment or internal state is detected that requires modulatory behaviour to be initiated (Eisenberger & Lieberman, 2004). The dorsal ACC (dACC) is also involved in the regulation of autonomic factors such as heart rate (Critchley *et al*., 2003).

The different components of ACC have traditionally been viewed as serving different cognitive functions. For example, the more rostral and sub-genual regions (BA25, 33, 24) have been viewed as playing more or a role in affective processing whereas the more dorsal regions (BA24, 32) have been more associated with cognitive control (Vogt, Finch & Olson, 1992, Devinsky, Morrell & Vogt, 1995, Bush, Luu & Posner, 2000, Margulies *et al*., 2007). Although such a broad distinction has been challenged by more recent work (Torta & Cauda, 2010), in relation to emotion regulation the traditional distinction implies that the more sub-genual regions might be involved in the generation or experience of emotion, whereas the more dorsal regions may be involved in detecting the need for action that is driven by the identification of an undesirable emotional state. It may also signal the requirement for regulatory action of the autonomic nervous system, and also of the prefrontal areas such as DLPFC.

## 1.4.2 Functional Magnetic Resonance Imaging (fMRI)

Our understanding of the neural substrates underlying the process of emotion regulation has been informed by a number of functional brain imaging techniques, primarily functional magnetic resonance imaging (fMRI). This technique gives a measure of brain activity by measuring the changes in blood flow throughout the brain. This is achieved due to the differential properties of oxygenated and deoxygenated blood, resulting in the blood-oxygen-level dependence (BOLD) signal (Ogawa & Lee, 1990). Areas of the brain which show a rise in the BOLD response are receiving an increase in oxygenated blood being directed towards them, reflecting the increased requirements of the underlying neuronal population for oxygen and glucose due to an overall increase in the area’s activity.

One distinguishing feature of the BOLD response is that it is comparatively ‘slow’ in nature (taking several seconds to arise). As a result, fMRI studies investigating the neural basis of emotion regulation have typically investigated emotion regulation that occurs on the scale of seconds (typically between 6 – 20 seconds) to take into account this inherent feature of the BOLD signal. However this has meant that such studies are in concordance with the notion of emotion as being a fairly short lasting state that is triggered by a specific stimulus and directed at a particular target (Beedie, Terry and Lane, 2005). A small number of imaging studies have looked at longer-scale mood regulation, such as the regulation of grief (Freed *et al.,* 2009), but this is not as comprehensively studied as ‘emotion’ regulation to date.

### 1.4.2.1 fMRI of emotion regulation

The first study to use fMRI to investigate the regulation of emotion, as typified as occurring on the basis of several seconds, was Beauregard, Levesque & Bourgouin (2001). This study identified the crucial involvement of the prefrontal cortex, particularly right superior frontal gyrus and right ACC, during the regulation of arousal elicited by sexually erotic films. Although this study differs from much of the subsequent neuroimaging literature on emotion regulation in that it dealt with the control of what might be described as ‘positive’ emotion, the study was highly influential in that it was the first to demonstrate that the control of certain aspects of emotional experience, particularly along the dimension of arousal, is underpinned by activation in regions of prefrontal cortex previously shown to be involved in executive function, planning, and response inhibition.

One of the first neuroimaging studies to investigate control of negative emotion (Ochsner *et al.,* 2002) involved participants viewing negatively valenced images for 4 seconds, followed by a period of reappraisal or non-regulation (‘attend’). The reappraisal instruction provided was that participants should reinterpret the image in such a way that they no longer felt negatively towards it. The contrast of reappraisal against attend trials, showing brain areas therefore more involved in regulation in comparison to attend, revealed recruitment of frontal cortex, particularly medial prefrontal cortex and areas of bilateral lateral frontal cortex (including DLPFC), during reappraisal of negative pictures. This was accompanied by decreased activity in the amygdala during regulation in comparison to attend. The findings of Ochsner *et al.,* therefore suggest that frontal areas, such as DLPFC, are actively involved in the formation of reappraisals that modulate the activation of structures such as the amygdala.

Schaefer *et al.,* (2002) used a similar paradigm to the Oschner study to demonstrate that activation of amygdala could also be *increased* through the use of emotion regulation strategies; activation of amygdala persisted for a greater period of time in response to maintaining negative affect elicited by negative pictures (i.e. up-regulation) compared to passive viewing (i.e. no regulation), and furthermore this was correlated with self-reported levels of affect that were obtained concurrently during the experiment. Although the role of the amygdala extends beyond that of simply an emotional ‘processor’, and indeed is also involved in non-intrinsically emotional processes such as person perception (Todorov & Engell,, 2008), such findings do suggest that activation in amygdala might be considered a valid measure of the level of negative emotion currently being experienced by the individual within such paradigms.

Phan *et al.,* (2005) used fMRI to investigate the down-regulation of negative emotion using cognitive reappraisal in a mix of male and female healthy participants. Highly arousing and negatively valenced IAPS images (International Affective Picture Set; Lang, Bradley & Cuthbert, 2005) were presented to participants in blocks of five, each being presented for 4 seconds. Throughout each block participants either maintained their response or used cognitive reappraisal to regulate their emotion to each image; specific strategies for emotion regulation were to either reinterpret the image in positive terms or to rationalise the content. Reappraisal-related activity was found within dorsal ACC, dorsal medial prefrontal and lateral prefrontal cortices, in addition to reduced activation in limbic areas such as basal ganglia and amygdala. Phan and colleagues also found that activity within dorsal ACC was inversely correlated with affect ratings that were collected concurrently during the experiment and a positive correlation within the amygdala, suggesting that the activity of the frontal and limbic regions during the process of reappraisal is related to the representation of emotion (limbic regions such as amygdala) and the subsequent top-down modulation of this emotional experience (frontal cortices).

Eippert *et al.,* (2007) further demonstrated that the direction of regulation (either up-regulation or down-regulation) of negative emotion was critical in either increasing (up-regulation) or decreasing (down-regulation) amygdala activity, providing further evidence that activity within amygdala can be taken as a useful indicator of emotional experience within such experimental contexts. This study, using a similar paradigm in fMRI, also demonstrated overlapping and distinct regions involved in down- and up-regulation of emotional experience; down-regulation was associated with a more left lateralised pattern of ACC, DLPFC and orbitofrontal cortex (OFC), whereas up-regulation showed less of a distinct lateralisation pattern. The authors suggest that this reflects slightly different processes being involved for up- and down-regulation, and the continued (and enhanced) experience of emotion in the up-regulation condition.

Goldin *et al.,* (2008) built upon these studies by investigating the relative time-course of prefrontal and limbic involvement in the down-regulation of emotion, specifically disgust, by strategies of cognitive reappraisal (antecedent focuses as defined by the process model, see section 1.2.1) and expressive suppression (response focused). Using fMRI the authors found that even though the use of expressive suppression and reappraisal both led to self-reported decreases in emotional experience, the relative contributions of the underlying brain regions were different. This study used a paradigm in which a group of healthy females were required to regulate their response to disgust-eliciting video clips by either reappraisal or expressive suppression (i.e. not letting any emotion show on their face). A no-regulation control condition was also included on certain trials. Cognitive reappraisal, in comparison to the control no-regulation condition, led to activation in a range of frontal areas including medial prefrontal cortex (mPFC), VLPFC and lateral OFC. The involvement of these areas was observed at an early stage of the regulatory process (i.e. during the first five seconds of regulation) and was associated with a later reduction in signal from amygdala and insula. Expressive suppression, by contrast, led to a later recruitment of a similar network of frontal regions; however there was no corresponding drop in amygdala and insula activity during the later time period which had been observed for reappraisal. These differences in neural contributions, and the differential effect upon subcortical regions such as amygdala and insula, can therefore help explain how cognitive reappraisal and expressive suppression may differ on a behavioural level (both strategies reduced negative emotional experience, though reappraisal more so than suppression) and on a physiological level (continuation of amygdala and insula activation during suppression reflecting continuation of the physiological component of the emotional response).

In support of the notion that the physiological manifestation of emotion experience might influence the brain activations underlying the process of emotion regulation, Ohira *et al.,* (2006) showed that medial OFC was involved in the regulation of accompanying peripheral physiological responses (such as skin conductance response) during the process of emotion suppression (though specific instructions as to how participants were to do this incorporated a mix of reappraisal and expressive suppression instructions).

Such studies therefore suggest that certain areas (particularly lateral frontal cortex) support the ‘cognitive’ aspects of emotion regulation, such as response inhibition and working memory, whereas other regions such as OFC might be more associated with the regulation of the accompanying physiological processes.

### 1.4.3 Connectivity

Recent studies have also begun to investigate more directly the connectivity of frontal and limbic regions during emotion regulation, to further elucidate the relationship between activation of the different areas. This has expanded on work such as Oschner *et al., (*2002), Schaefer *et al.,* (2002) and Eippert *et al.,* (2007) that identified how the level of activation in amygdala was often negatively correlated with activation of frontal cortex, by investigating whether such negative correlations are due to the nature of the connectivity between the regions. Connectivity approaches in fMRI research are broadly defined as either measures of functional connectivity (i.e. areas whose activity is correlated across a particular time-frame) or effective connectivity (the way in which activity within area X can be said to be exerting a causal influence on area Y).

Banks *et al.,* (2007) used a psychophysiological interaction analysis approach to demonstrate the coupling of frontal and amygdala responses during cognitive reappraisal. A psychophysiological interaction analysis investigates whether the correlation in brain activity between two brain areas is different under different experimental conditions (such as emotion regulation or no regulation). Psychophysiological interaction analyses have been said to bridge the gap between functional and effective connectivity measures (Friston *et al.,* 1997). Within the cognitive reappraisal paradigm used by Banks *et al.,* (2007), the degree of coupling of activity in OFC and dorsomedial PFC to amygdala predicted the extent of decrease in emotion experience related to reappraisal, therefore providing evidence that the down regulation of limbic response by frontal areas may in part underpin the process of regulation.

The modulation of limbic regions by prefrontal cortex during successful emotion regulation is also predicted by measures of habitual cognitive reappraisal use, whereby increased activity in prefrontal regions and decreased activity in amygdala was found for individuals who reported a greater typical use of reappraisal (Drabant *et al.,* 2008). This therefore suggests that the cortico-subcortical interactions underlying emotion regulation might change as a result of continued usage, to such an extent that a behavioural effect can be predicted from the underlying interaction.

Other approaches have attempted to bridge the gap between measures of functional and effective connectivity methods by using functional connectivity methods that are informed by knowledge of known anatomical projections and connectivity. Approaches such as this have been commonly used to examine questions pertaining to the connectivity of different brain areas in emotion regulation. One way of investigating such processes using fMRI is by using mediation analysis to trace the pathways by which successful or unsuccessful regulation can occur (Wager *et al.,* 2008). Mediation analysis investigates how activation in a particular neural pathway might be affected by an aspect of the behavioural task (in this example, whether or not the emotional experience was being regulated). Wager *et al.,* (2008) further investigated the specific cortical-subcortical interactions which underlie the process of regulation (specifically reappraisal) by using pathway mapping. During the down-regulation of negative images it was found that activity in right VLPFC correlated with ‘successful’ down-regulation. The mediation analysis revealed a pathway through the nucleus accumbens associated with successful regulation, and a pathway through amygdala for less successful regulation (i.e. increased emotion experience). The involvement of nucleus accumbens was particularly noteworthy and suggested that the process of successful regulation, that involves positive appraisal of the stimuli, may be underpinned by activity within the ventral striatum and nucleus accumbens. Such a finding supports the notion that the ventral striatum does play an intrinsic role in emotional behaviour (Levita *et al.,* 2009). The pathway underpinning unsuccessful regulation also further suggests that down regulation of activity within amygdala is a defining feature of the ‘extinguishing’ of an emotional response, given that unsuccessful regulation was associated with its continued activation.

## 1.5 Types of reappraisal

In the studies that have been discussed in the preceding sections, an imprecise and sometimes conflicting definition of the exact processes that constitute cognitive reappraisal has been employed, with descriptions ranging from ‘active’ reinterpretations based on situational context (e.g. “reappraise the picture as if you were a medical professional”), to more ‘passive’ processes of general-detachment and distancing (e.g. “take a detached perspective”). Recent work has begun to investigate neural differences underlying these similar yet distinct processes. McRae *et al.,* (2010) provided the first direct comparison of more ‘active’ cognitive reappraisal and ‘passive’ distraction. This study used a similar paradigm to Oschner *et al.,* (2002) that required participants to down-regulate their responses to negatively valenced pictures (selected from the IAPS) using strategies of reappraisal or distraction. The results showed that reappraisal was more effective than distraction at reducing experiential affect and was associated with increased activation of mPFC compared with distraction. However, despite being a less ‘effective’ strategy, distraction was associated with greater reduction in activity within the amygdala than reappraisal, in addition to prefrontal and parietal regions. This therefore illustrates subtle, yet significant, differences in the experiential and neural components of the two techniques. This complements findings that an increased ‘processing load’ of task irrelevant information (i.e. a form of distraction) during emotion processing led to a similar pattern of increased DLPFC and reduced amygdala activation as for distraction in the McRae *et al.,* study (Mitchell *et al.,* 2007). An increased standardization of emotion regulation instructions would increase the ability of studies to inform conclusions about what specific mechanisms of emotion regulation are being recruited beyond just those involved in more general cognitive processes.

### 1.5.1 How does the type of emotion influence the neural basis of emotion regulation?

Most imaging studies have primarily focused on the regulation of ‘negatively’ valenced emotion, such as fear, disgust and sadness. This is primarily due to the relative ease of elicitation of such emotions in an experimental situation, and also because of the prevalence of undesirable negative emotion in psychiatric illness such as major depression (e.g. Cooney *et al.,* 2010). There have, however, also been a number of studies investigating the control of positive emotional experience. Mak *et al.,* (2009a) found differences, particularly in prefrontal regions, in activation related to the regulation of positive and negative emotion elicited by pictorial stimuli. Although there were a number of overlapping area of activation, regulation of negative emotion involved the ACC to a greater degree. This was speculated to be associated with the behavioural finding that regulation of positive emotion was considered, by participants, to be more effective at achieving the regulatory goal than when regulating negative emotion (i.e. regulating positive emotion is ‘easier’.). This fits in with the posited broader role of the ACC in being involved in the ‘neural alarm’ system of the brain (Eisenberg & Lieberman, 2004), whereby the ACC is involved in signaling the requirement for regulatory action; thereby the increased difficulty of regulating negative emotion might be driving the need for recruitment of such an ‘alarm’ system.

Ochsner *et al.,* (2004) also expanded on the traditional investigation of down-regulation of negative emotion by investigating both the up- and down-regulation of negative emotion. This was achieved by strategies of either focusing on the self relevance of the picture (up-regulation) or by reappraising (down-regulation). Up-regulation was particularly marked by activation in rostromedial prefrontal cortex and increased amygdala activation, in comparison to reappraisal which preferentially recruited right lateral and OFC and attenuated amygdala activity. This study therefore demonstrated that although both strategies were essentially a form of cognitive reappraisal, there were distinct activations related to the mechanisms underpinning them, such as involvement of areas involved in introspective processing for the up-regulation (e.g. mPFC), and involvement of regions involved in externally-focused processing during the down-regulation (lateral frontal cortex). This also suggests that emotion regulation is not always underpinned by the same systems, but may rely on difference systems according to the direction of regulation, and the valence of the emotion (Mak *et al.,* 2009a).

Kim and Hamann (2007) utilized a design that involved the up- and down- regulation of both negative and positive emotional images. Down-regulation, regardless of valence, recruited a more bilateral pattern of frontal activation compared to up-regulating emotional response. Decreasing negative emotion resulted in activation in lateral PFC, dorsomedial PFC, bilateral-medial OFC, right lateral OFC, and bilateral ACC in comparison to decreasing positive emotion, with no significant differences observed for up-regulation in comparison to down-regulation. Increasing positive emotion was associated with left rostromedial PFC, left lateral PFC, right VLPFC and the left amygdala. This again provides further support that the neural basis of emotion regulation is dissociable based on the direction of regulation, and for the valence of the emotion to be regulated. It is worth noting, however, that this study only studied these effects in a sample of females. Therefore it is not possible to conclude that the same pattern of results would necessarily be found in males; indeed the literature would suggest underlying differences in the neural processes involved in emotion regulation for males and females (Mak *et al.*, 2009b, Koch *et al.*, 2007; see section 1.6.1).

Studies have also begun to investigate other dimensions surrounding the exact ‘type’ of emotion. For example, differences have been reported for down regulation of moral (e.g. someone threatening another person) compared to non-moral (both individuals threatening each other) emotion-eliciting pictures in mPFC, suggesting the specific content of stimuli may affect the manner in which regulatory systems are engaged (Harenski & Hamann, 2006).

## 1.6 Individual Differences

### 1.6.1 The role of gender in emotion regulation

Despite mounting evidence of differences in brain function between males and females in a variety of fields, particularly those related to social cognition (Cahill, 2006) comparatively few studies have systematically investigated differences between males and females in the neural correlates of emotion regulation. This is despite the fact that studies show differences in emotional responding itself between males and females (Gard & Kring, 2007; Hamann & Canli, 2004; Yuan *et al.,* 2009). Differences in emotional responding have also been suggested to be underpinned by connectivity of amygdala to other brain areas in a resting state (i.e. task independent) (Kilpatrick *et al.,* 2006).

A number of studies have begun to explore potential differences in the neural underpinnings of emotion regulation in males and females. McRae *et al.,* (2008) focused on differences between males and females in down-regulation of negative emotion using cognitive reappraisal. Despite similar experiential ratings following regulation, males showed less activation of prefrontal areas compared to females, but greater decreases in amygdala activity. This could have either reflected increased effort by females during reappraisal, or that females may have used more positive emotions as ‘interference’ during the down-regulation. Regardless of interpretation, the study clearly demonstrates differences in brain activation between the two groups despite comparable self-report ratings of emotional experience.

Another study by Domes *et al.,* (2009) found differences between males and females in experience of (greater amygdala activity in females) and conscious regulation of (reduced OFC, ACC and DLPFC activity in females) emotion. This study also investigated ‘up-regulation’ of negative emotion, finding that males were more ‘effective’ at this; represented by an increase in amygdala activity and recruitment of frontal areas. This led the authors to propose an alternative to the more traditional view of male aggressive behaviour being due to a lack of inhibition (possibly related to lack of inhibition by OFC) and emotion down-regulation, in that it might also be due to an increased likelihood of ‘up-regulating’ negative emotion. However further studies investigating both up and down- regulation of negative emotion would be required in order to support this suggestion.

Mak *et al.,* (2009b) also found commonalities and differences between brain activations in males and females during regulation of emotion. Males particularly showed increased activity in frontal regions, such as left DLPFC and lateral OFC, during regulation of negative emotion compared with females. It has been proposed that such differences (and differences identified in the studies previously reviewed) might provide a basis for an explanation for the increased vulnerability of females for developing affective disorders, such as depression (Mak *et al.,* 2009), whereby an impaired ability to adequately recruit frontal areas involved in the successful down-regulation of emotion may lead to a sustained, and potentially pathological, maintenance of undesirable emotional states.

## 

### 1.6.2 Emotion Regulation in children

Given what has been revealed about the crucial role that the frontal cortex plays in the successful regulation of emotion, it is likely that development of emotion regulation ability is related to maturation of frontal cortex during childhood, and continued myelination of the frontal cortex throughout adolescence, given the prefrontal cortex’s role in emotion regulation and cognitive control more generally (Thompson-Schill, Ramscar, & Chrysikou, 2009).

One study showed that the development of connectivity between frontal cortex and amygdala in adolescence is critical to developing an adaptive regulatory ability, and that this may be in response to hyper-responsiveness in emotional reactivity displayed in adolescence (Hare *et al.,* 2008). An emotion regulation fMRI paradigm in young girls (aged 8-10) yielded more widespread areas of frontal activation compared to adult women during an identical paradigm (Levesque *et al.*, 2003) comprising the reappraisal of sadness-eliciting film clips. The authors proposed that this reflected a greater amount of cognitive effort due to less well-structured connectivity between frontal and limbic regions (Levesque *et al.,* 2004) in younger participants.

### 1.6.3 Emotion Regulation in later adulthood

There is a growing body of work that suggests changes over time into later-adulthood in the way that emotion regulation occurs both experientially and in terms of its neural underpinnings. Urry *et al.,* (2006) found that although older participants (aged 60+) showed a similar pattern of widespread PFC and amygdala activity to that typically shown by younger samples when up-regulating their negative affective response to aversive pictures, down-regulation (using reappraisal) did not produce as robust a pattern of inversely-coupled PFC and amygdala activation as observed in younger adults. However on an individual basis, older participants who did show a reduction in amygdala activity during down-regulation showed an inverse pattern of coupling with ventromedial PFC; this coupling was associated with reductions in negative affect and also subsequently with diurnal cortisol secretion throughout the 1-week period following the scan. This therefore suggested that older participants who were able to down-regulate their amygdala response more effectively were more likely to experience favourable outcomes in terms of typical cortisol secretion, which the authors suggest is associated with health and well-being outcomes.

Winecoff *et al.,* (2011) showed that the prefrontal and amygdala activity during cognitive reappraisal (specifically ‘distancing’) were the same for a group of older and younger adults, with younger adults showing additional activation in inferior frontal gyrus and superior temporal gyrus. The study suggested that, regardless of age, the ability to regulate is more related to individual cognitive ability rather than age; a conclusion supported by the fact that the study recruited two prospective age samples who were matched for demographics such as years of education and mini-mental state examination (a test of cognitive impairment).

Such research in younger and older populations has demonstrated the way in which emotion regulation ability is dependent on maturation of relevant brain structures (such as frontal cortex), and how the processes might change, particularly in terms of cognitive effort, over later adulthood.

### 1.6.4 Personality

Imaging studies have also investigated the extent to which the neural bases of emotion regulation are modified by various personality factors. Harenski, Kim & Haman (2009) demonstrated increased activation of both amygdala, and subsequently DLPFC in individuals with high trait neuroticism during a down-regulation paradigm. Individual differences in emotion regulation are also strongly related to personality factors such as attachment anxiety (Gillath *et al.,* 2005).

The relationship between personality and emotion regulation has also been investigated in terms of motivation to regulate; Tamir (2009) found that introverts were less likely to report motivation to engage in effortful up-regulation of positive mood than extroverts. Although down-regulation of negative affect was not investigated, this finding provides a rationale for why the neural underpinnings of emotion regulation might differ in either pattern or extent of brain activations for different personality types.

## 1.7 Ecologically valid emotion regulation

There has been a recently emerging emphasis on exploring emotion regulation processes in situations of increased ecological validity. One such method has been to utilize paradigms that involve the recall of autobiographical memories that serve to elicit emotion, which can subsequently be cognitively controlled using processes such as reappraisal. One such paradigm (Kross *et al.,* 2009) had participants recall negative autobiographical memories which were then either maintained (‘feel’ strategy) or regulated (‘analyze and accept’ strategy). The study conceptualised the ‘feel’ strategy as a more adaptive means of behaviour, whereas the ‘analyze and accept’ strategy was thought to be more akin to a maladaptive strategy of rumination that is prevalent particularly in major depressive disorder (Cooney *et al.,* 2010). Both strategies were associated with activation of left prefrontal cortex, supporting the emergent view of lDLPFC as being involved in the more general cognitive processes associated with emotion regulation (Golkar *et al*., 2012). The ‘analyze and accept’ strategy was associated with activation of regions such as mPFC and subgenual ACC (sgACC) which may relate to the ruminative and ‘self referential’ components of that strategy.

Another study (Nili *et al.,* 2010) attempted to elucidate mechanisms of fear regulation during a ‘real-life courage’ task in which participants could choose to bring a real snake either closer-to or further-away from themselves whilst undergoing fMRI scanning (the real snake was in a box on a conveyor belt that could be moved closer towards or further away from the participant as they lay in the scanner). Decisions to bring the snake closer were associated with increased activation of sgACC, which had previously been implicated in down-regulation of emotion, and was suggested by the authors to play a central role as a common mediator of emotion regulation in the absence of specific instructions towards a particular strategy.

Such investigations of more ecologically valid forms of emotion regulation clearly hold promise in being able to inform us further of how the neural basis of emotion regulation operates in everyday life. However such investigations for now remain relatively isolated and therefore lack the weight of evidence to sufficiently synthesize evidence from a number of studies investigating the same concept.

## 1.8 Meta-analysis of emotion regulation

One approach that has been able to synthesize evidence from a number of different closely-related studies has been the meta-analytical study of voluntary cognitive reappraisal. Kalisch (2009) performed a meta-analysis on a number of brain imaging studies that involved the down-regulation of negative emotion by cognitive reappraisal. This analysis revealed widespread activations of bilateral and medial frontal cortex during the period of reappraisal.

### 1.8.1 Temporal aspects of emotion regulation

On the basis of this analysis Kalisch proposed a model of cognitive reappraisal, the Implementation-maintenance model (IMMO), which takes into account the temporal relationship between the different processes involved during the process of reappraisal, such as initial stimulus appraisal, behavioural response generation, etc. The model also provides an account of the processes that the brain areas identified in neuroimaging studies of emotion subserve, such as initial engagement of cognitive control processes (left and posterior MFC), response inhibition (right posterior LFC, and OFC), working memory and goal maintenance (wide areas of medial and lateral FC), and monitoring processes (right anterior LFC). Although the model provides a parsimonious account of the relative contributions of these brain areas to the different facets of reappraisal, further empirical testing is required to directly confirm this. The first study that addresses this model directly has recently been published (Paret *et al.,* 2011) and finds evidence for dissociable activations in relation to the time-course of reappraisal. Specifically activation in the early stages of reappraisal (the ‘implementation phase’) was observed in left posterior frontal cortex, which shifted to right anterior portions during later stages (the ‘maintenance phase’). However it is still not possible to be confident of exactly what cognitive processes each region might be supporting.

### 1.8.2 What does each brain region do during reappraisal?

A recent paper from Golkar *et al.,* (2012) attempted to parse the different contributions of different brain areas to the process of reappraisal. This study adapted a standard emotion regulation paradigm of IAPS images and required participants to perform cognitive reappraisal or passive viewing to both negative and neutral images. Activation was found within the DLPFC across reappraisal to both image valence types (negative and neutral), whereas activation within the lateral OFC (BA10) was only observed for the regulation of negative pictures. The authors suggested that the role of the DLPFC in cognitive reappraisal is one of more general cognitive control (perhaps related to effortful attentional demands of the task) whereas the role of OFC seems to be more specifically related to emotional control, given the regions anatomical connectivity with the amygdala.

Such investigations have advanced our understanding of the neural basis of emotion regulation by providing an investigation of how the temporal aspects of emotion regulation are reflected in the neural underpinnings, and also attempt to provide further links to the specific cognitive processes that specific regions are supporting.

## 1.9 Stimulus presentation

In addition to the separable neural activations which support different cognitive process and different temporal stages of emotion regulation, a number of investigations have also suggested that anticipatory and ‘actual’ processing of emotional material may also be dependent on different systems. Anticipation of emotional material (i.e. no visual stimulus) has been shown to be associated with activation in ACC and parieto-occipital sulcus, compared to a more ‘traditional’ network of amygdala, insula, medial and lateral prefrontal cortex, cerebellum, and occipito-temporal areas for perceptual processing of emotional material (Bermpohl *et al.*, 2006, Herwig *et al.,* 2006). Furthermore, it has been demonstrated that the neural processes representing emotional experience may be engaged prior to the actual experience of the emotional state (Prohovnik *et al.,* 2004).

Studies have also investigated emotion regulation during the ‘preparatory’ phase of anticipating emotional stimuli, and found broadly similar patterns of increased activation in DLPFC and mPFC with reduced activation in amygdala and insula to previously described studies of emotion regulation during presentation of affective stimuli (Herwig *et al.,* 2007). This demonstrated that in certain circumstances the neural processes underlying emotion regulation can be engaged even during the expectation of an emotion-eliciting event.

## 1.10 Interpersonal Emotion Regulation

Another distinction between different aspects of emotion regulation can be made on the basis of whose emotions are targeted in the regulation attempt. The ability to adaptively control one’s own emotional experience might be termed ‘intrapersonal emotion regulation’. However in addition to controlling our own emotional experiences we are also capable of using strategies to attempt to influence the emotional states of other people. This process can be defined as ‘interpersonal emotion regulation’ (Niven, Totterdell & Holman, 2009). For example, if a friend is sad then one might try to help them to think about the situation differently in an effort to change his or her emotional response to the situation and thereby alleviate the sadness.

The work discussed thus far has concerned the neural underpinnings of emotion regulation as targeted towards one’s own emotions (intrapersonal emotion regulation). Recently, however, attention has fallen on establishing how emotional regulatory processes can be applied not only to the self (intrapersonal emotion regulation) but also to an external person (interpersonal emotion regulation) (Niven, Totterdell & Holman, 2009). These two processes have also been described within the literature as ‘intrinsic’ (self regulation) and ‘extrinsic’ (regulation of another) (Werner & Gross, 2010). Interpersonal (or extrinsic) emotion regulation is the process of influencing the internal emotional state of another individual, and as with intrapersonal emotion regulation is said to occur both at an automatic and conscious level (Totterdell *et al.,* 1998). More automatic forms of interpersonal emotion regulation are conceptualised in terms of affect ‘spreading’ within social groups (Totterdell *et al.,* 1998) whereas more conscious regulation involves a more active process of intended regulation performed by the individual directed to the other individual.

Niven, Totterdell & Holman (2009) identified a classification of interpersonal emotion regulation strategies that an individual might employ, based on whether the goal of the regulatory process is to worsen or improve the affect of the target individual, and whether processes are engaged in a situational state (i.e. focus on affective state of target individual), or in a relationship state (focus on relationship with the target individual).

However despite this recent interest in interpersonal emotion regulation the neural basis of interpersonal emotion regulation is completely unexplored. The first study in this thesis was therefore designed to probe the neural correlates of interpersonal emotion regulation. The second research question of this thesis is designed to investigate how different strategies for emotion regulation that differ in their effortful nature might be reflected by differing neural underpinnings.

## 1.11 Automaticity and emotion regulation

A key distinction between controlled and automatic emotion regulation is that controlled emotion regulation requires more effort than automatic regulation. However an unexplored question is whether such effortful strategies (‘goal intentions’) have a comparable neurophysiological basis to strategies that may be considered more automatic, or less effortful, in their nature. A corpus of work now exists investigating the neural basis of effortful emotion regulation (e.g. Banks *et al.*, 2007; Kalisch, 2009) and particular types of strategy therein (e.g. Goldin *et al.*, 2008, McRae *et al.,* 2010). Such investigations have revealed that a variety of effortful strategies such as cognitive reappraisal, expressive suppression, and distraction, rely upon a variety of prefrontal areas such as DLPFC and ACC for their successful implementation. Furthermore the efficacy of such strategies in reducing emotional experience has been shown to be driven by the modulatory influence of such frontal regions over subcortical areas such as the amygdala (Banks *et al.*, 2007, Johnstone *et al.*, 2007).

Such effortful strategies as these can be defined as ‘goal intention’ strategies. Goal intentions are strategies for goal attainment that specify a particular performance or desired end state (Gollwitzer, 1993). However crucially such strategies contain a level of ambiguity in the manner by which an individual might achieve those outcomes. The extent to which this ambiguity occurs is variable; when related to emotion regulation it might refer to a desired outcome as vague as ‘try to feel’ less emotional. Other examples, such as those used in neuroimaging investigations mentioned previously (based upon the instructions developed by Gross, 1998), have a more specific mechanism of attaining the desired outcome state of feeling less emotional, for example by instructing the individual to take a detached and unemotional perspective. However such an instruction still contains a level of ambiguity (i.e. how exactly should a detached perspective be taken?). Additionally the link formed between this particular behaviour and a particular trigger for its initiation may remain weak. It is clear, however, that the adaptive control of emotion not only relies on the individual’s ability to engage in voluntary emotion regulation but also to be able to control their emotions in a more automatic fashion.

A precise definition of automatic emotion regulation is somewhat problematic. Some studies, such as Mauss, Bunge & Gross (2007), have conceptualised ‘pure’ automatic emotion regulation along the dimensions of decision making, awareness and controllability. Specifically, they propose that automatic emotion regulation occurs without a conscious decision to engage in the goal-driven regulatory process, without attention being focused on the regulatory attempt, and without the exertion of effortful control mechanisms. However the authors also acknowledge that emotion regulation might exist on a continuum between the ‘automatic’ and ‘deliberate’. This therefore makes the concept of ‘automatic’ emotion regulation somewhat vague. Mauss, Bunge & Gross (2007) also argue that automatic emotion regulation can exert effects at any point along the emotion generative process, as conceptualised by the process model of James Gross (1998, 2002). Specifically this states that automatic emotion regulation can alter the attentional deployment to stimuli, appraisal and reappraisal processes, and antecedent focused regulation of emotion (i.e. suppression). Although no mention is made of situation selection and situation modification, presumably these processes could also operate with some level of automaticity; the review seems to hint at this by discussing how avoidant attachment styles in childhood may relate to emotion regulation processes (Cassidy, 1994). Attachment could, perhaps, be considered to be a form of situation selection or modification.

### 1.11.1 Development of Automatic Emotion Regulation

The way in which more automatic forms of emotion regulation develop is also thought to be dependent on early experience, with strategies that are then used on a habitual basis throughout the life span becoming highly automatised. This is due to the basic idea that any skill that is repeatedly practiced eventually becomes more automatic in nature (e.g. Bargh & Chartrand, 1999).

There are some emotion regulation studies that have examined automatic emotion regulation on the basis of which strategies participants engaged in without being specifically instructed to do so (e.g. Ehring *et al.*, 2010). However, it is unclear as to the exact basis on which such strategies might be defined as automatic; although the spontaneous use of regulatory strategies might operate in the absence of a specific goal or instruction to regulate, they may nevertheless operate with attention on the regulation, in a controlled fashion and with a conscious decision to engage in them (such studies are complicated further by the fact that they rely on self reports of participants; strategies they recall can be said to not feature key aspects of automaticity). However the use of such strategies might meet a definition for automaticity in terms of their habitual use (i.e. that the strategies people use in everyday life are more practiced, therefore more efficient, and more ‘automatic’).

## 1.12 Modulation of emotion regulation

Given that the neural correlates of voluntary intrapersonal emotion regulation (emotion regulation of the ‘self’) are beginning to become increasingly well understood, a pertinent research question that also emerges is whether the manipulation of the activity within the brain areas known to be involved in voluntary emotion regulation might result in a modification of the ability of an individual to engage in emotion regulation (or the effectiveness of emotion regulation). Although investigations into the neural basis of voluntary emotion regulation (e.g. Goldin *et al.,* 2008, Oschner *et al.,* 2002) have revealed the neural systems that are associated with these processes, a causal relationship cannot necessarily be inferred. This is due to the fact that fMRI (and other many other neuroimaging techniques) remains, in many respects, a correlational technique in that activation within a particular brain area might correlate with the manipulation of a psychological variable (e.g. an instruction to perform emotion regulation) but cannot be said to ultimately be responsible for the behavioural effect. One such methodological approach that does have the ability to further investigate the causal role of a brain area to psychological processes of interest is brain stimulation methods such as Transcranial Magnetic Stimulation (TMS) and Transcranial Direct Current Stimulation (tDCS). This is due to these techniques’ ability to directly manipulate the function of a particular area of the brain, which then allows for an investigation of how performance on a psychological task of interest (e.g. an emotion regulation task) might be causally affected by such manipulation. Such techniques have been considered to offer a ‘virtual lesion’ approach to investigating brain functioning (Pascual-Leone, Walsh & Rothwell, 2000); stemming from approaches that have used patients with brain damage or lesions in order to make inferences about the contribution of particular brain areas to an individual’s functioning.

Any demonstration of a causal effect of an area of the brain’s activity on a phenomenological process would, therefore, add much further weight to any claims for the importance of that region’s specific role in that particular process of interest, such as emotion regulation. Furthermore, any demonstration that the ability to regulate emotion might be altered by brain stimulation may have clinical relevance for psychiatric disorders typified by deficits in emotion regulation, such as depression.

A further aim of the thesis was therefore to investigate whether or not such brain stimulation methods could be used to produce a demonstrable effect upon voluntary emotion regulation functioning. Chapter 4 describes the technique of tDCS in further detail, discussing its use in research to date. The chapter will also then describe investigations into how the technique could be used to alter the ability of healthy individuals to perform ‘voluntary’ emotion regulation under certain parameters of stimulation.

# Chapter 2 – the neural correlates of intrapersonal and interpersonal emotion regulation

**This chapter describes the process of developing a paradigm designed to investigate the neurophysiological underpinnings of both intra- and interpersonal emotion regulation using fMRI. This includes the results of comprehensive piloting developing both the stimuli and experimental paradigm. The chapter will then go on to describe an fMRI experiment that used this paradigm to probe the neural underpinnings of interpersonal emotion regulation. The findings of the experiment are discussed in the light of the relevant literature on the neural basis of emotion regulation and social cognition.**

Chapter 1 provided an overview of the concept of emotion regulation and reviewed the relevant literature on the neural basis of emotion regulation to date. This review revealed several key questions that have not yet been adequately addressed within the literature. The first of these questions was based on the emerging behavioural literature on the concept of interpersonal emotion regulation; that is emotion regulation where the target of the regulation is another person’s emotions rather than (or in addition to) one’s own. Although the prevalence of interpersonal emotion regulation in everyday life is now well established (e.g. Niven, Totterdell & Holman, 2009), to date there have been no studies investigating the neural underpinnings of interpersonal emotion regulation, and to what extent these may differ or share similarities with intrapersonal emotion regulation. Given the paucity of such research Chapter 2 therefore describes the development of a study designed to probe this question.

There have been no existing studies that have investigated interpersonal emotion regulation using fMRI. By examining the existing literature on the neural basis of a number of closely related areas, both from neuropsychological and neuroimaging literature, a number of candidate regions of the brain that might be involved emerge. Many of these processes are also involved in intrapersonal emotion regulation; conscious (controlled) interpersonal regulation is likely to involve overlap with intrapersonal regulation, in that an individual whose aim is to regulate the emotional state of another person might first consider how they would effectively regulate that emotional state themselves.

One particular candidate region that might play a role in interpersonal emotion regulation is the OFC, based on its known role in monitoring of behaviour. Lesions to the OFC have been shown to lead to deficits in the ability to self-monitor emotional processing (Beer *et al.,* 2006). It is therefore likely that the OFC will be involved in both regulation of self (intrapersonal) and other’s emotion (interpersonal) which involves such self-monitoring processes (research reviewed in section 1.4.2 of Chapter 1 has revealed a role for OFC in intrapersonal emotion regulation). In particular it is the role of the OFC in monitoring that may be particularly implicated in interpersonal emotion regulation, given that this requires monitoring of the other person’s state in order to develop a plan to regulate their emotion. The OFC is therefore one area that might play a greater role in interpersonal than intrapersonal regulation.

The rostral medial prefrontal cortex is another area that might be involved in interpersonal regulation due to its known role in a variety of social cognition processes. It has been implicated in appraisal of personality traits of either the self or other, with activation correlated with perceived similarity between the self and other in terms of personality traits (Benoit *et al.,* 2010). Rostral medial prefrontal cortex may therefore be involved in appraising the emotional state of the self (intra) and other (inter), a process considered key to successful completion of both tasks. Studies have also shown that vmPFC is involved in the process of making more general distinctions between the ‘self’ and ‘other’ (Powell *et al.,* 2010), as well as frontopolar cortex (Raposo *et al.,* 2011). Such distinctions would likely be crucial in an experimental task which involved manipulating the target of a process from the ‘self’ to ‘another’ person.

When considering what other aspects of social cognition might be involved in the process of interpersonal emotion regulation, it is also likely that the a process of interpersonal emotion regulation that involves seeing another person in an unpleasant emotional state might invoke feelings of sympathy for that person. Conceptually this might then in turn provide a motivation for the individual to attempt to regulate the conspecific’s emotional state. This would fit in with some general theories that propose that altruistic behaviour can emerge from others’ suffering (Staub & Vollhardt, 2008). Areas of the brain previously been shown to be involved in affective and ‘shared representation’ networks, such as right inferior parietal cortex and regions involved in experience of emotion, such as amygdala (Decety & Chaminade, 2003) might provide a parsimonious set of regions that might therefore be involved in the representation of ‘sympathy’ for another.

The ability to take the perspective of another person is another intrinsic component of interpersonal emotion regulation; advising another person how to regulate their emotional state might first require the individual to make judgments as to how they would regulate their own emotions in the same situation. Jackson *et al.,* (2006), in an fMRI study, presented images of limbs in painful situations, to which participants were required to make judgments of how painful they themselves or another person would find it. Common brain activations between conditions were found in traditional ‘pain processing’ networks including ACC and anterior insula. Judgments for the ‘other’ condition preferentially recruited areas of posterior cingulate and right TPJ. Seger *et al.,* (2004) also used fMRI with a paradigm that required participants to make judgments related to food preferences for themselves or another person. They found that ‘other’ judgments recruited superior medial parietal areas and left lateral frontal cortex to a greater extent than for the ‘self’ judgments. All of these areas therefore might contribute towards the process of interpersonal emotion regulation to a greater extent than intrapersonal regulation.

This ability to take another person’s perspective during interpersonal regulation also overlaps with the concept of ‘theory of mind’. Theory of mind, or ‘mentalising’, refers to the ability to attribute mental states such as intentions, beliefs and desires to another person (effectively a form of ‘perspective taking’; Premack & Woodruff, 1978). While brain imaging research has consistently identified a network of brain regions involved in theory of mind such as mPFC, temporal poles, and superior temporal sulcus (STS) (Gallagher *et al.,* 2000, Vogeley *et al.,* 2001), the left TPJ has also been implicated on the basis of lesion studies (Samson *et al.,* 2004) and recent imaging studies and meta-analyses (Van Overwalle & Baetens, 2009). Recent work also supports the specific role of TPJ in mentalising tasks rather than just in orienting attention to unexpected stimuli (Young *et al.,* 2010).

Seidel *et al.,* (2010), demonstrated an interesting dissociation of lateralization of TPJ activation during a task in which participants were required to read a series of vignettes which described positive or negative social situations, and then decide whether to attribute responsibility for the situation to either themselves or another person. Attributions to the ‘self’ resulted in a right lateralized pattern of TPJ activation, whereas attribution to another person was confined to the left TPJ (as well as precuneus and medial frontal gyrus). Therefore it is possible that interpersonal emotion regulation might be associated with activation of left, rather than right, TPJ, as a function of the change in target of the regulation to another rather than the self.

## 2.1 Differences between intrapersonal and interpersonal emotion regulation

The process of interpersonal emotion regulation seems likely to differ from the process of intrapersonal emotion regulation in a number of ways. In particular, interpersonal emotion regulation incorporates a number of aspects of social cognition (the processes underlying social perception, engagement and interaction) that have not necessarily characterized intrapersonal emotion regulation. Specifically, interpersonal emotion regulation involves the identification of the other person’s current emotional state, based on contextual cues such as the presence of an emotion-eliciting stimulus, as well as bodily information such as facial expression. Secondly, having identified the other person’s emotional state, the affective component of empathy may be needed to mirror an equivalent affective state in the ‘self’ (Preston & De Waal, 2002; Hooker *et al.,* 2010). Having simulated a shared affective state, the cognitive component of empathy may then be required to take the perspective of the other person. This cognitive component of empathy might be considered akin to ‘theory of mind’ or ‘mentalizing’ (Premack & Woodruff, 1978; Gallagher *et al.,* 2000; Frith & Frith, 2003). Finally, monitoring may also be required in order to assess whether the regulation attempt has had the desired effect upon the target’s emotional state. Despite these conceptual differences between the processes of intra- and interpersonal emotion regulation, it is not currently known to what extent the neurophysiological processes supporting these self and other foci differ.

To date no studies have investigated the neurophysiological underpinnings of interpersonal emotion regulation using fMRI. Disentangling the two complementary emotion regulation systems (intrapersonal and interpersonal) may ultimately shed light onto which groups may be impaired in interpersonal regulation, and how these deficits might be underpinned, and ultimately treated.

## 

## 2.2 Stimulus development

The first stage of the process was to identify a set of stimuli that could be used in order to elicit emotional reactions from participants. These stimuli would have to be suitable for use in behavioural and fMRI experiments given that the paradigm was ultimately designed in such a way that would be taken into an fMRI experiment.

Short video clips were selected as the method used to elicit emotional responses. This was for three main reasons. Firstly, it has been argued (Rottenberg, Ray & Gross, 2007) that video clips are capable of eliciting emotional responses that are stronger than still images on a multi-domain basis (experientially, behaviourally and physiologically). Secondly, the use of video clips would constitute a more ecologically valid task, akin to real life where individuals encounter dynamically unfolding situations rather than a series of still images. This was considered to be a particular issue with regards to the interpersonal interaction that would have to form a crucial component of the interpersonal emotion regulation task. Specifically it would require the participant to use the unfolding events as a basis for the choice of regulatory outcome they would apply to the other person. Finally, it had been shown that much of the brain activations, particularly within prefrontal cortex, shown by emotion regulation to still images could largely be accounted for by changes in visual fixation (Van Reekum *et al.,* 2007). Video clips could potentially reduce the capacity for this confound by presenting a dynamically moving stimulus, whereby a regulatory process achieved by focusing on non-salient aspects of the stimuli would be less feasible.

### 2.2.1 Methodology

A large sample (N=60) of stimuli was obtained from commercially available films (e.g. films used in other investigations, such as Gross, 1998), and from websites such as *YouTube*. Stimuli were digitized and cut to durations of 10 seconds using *Adobe Premier Elements* (version 7.0, Adobe Systems, San Jose). A duration of 10 seconds was chosen as this would be in accordance with many previous investigations of intrapersonal emotion regulation (e.g. Oschner *et al.,* 2002, Goldin *et al.,* 2008); one of the key factors with regards to design of the interpersonal paradigm would be that it would follow on from established work on intrapersonal regulation.

N = 34 (8 male) undergraduate Psychology students rated the films for their ability to elicit emotional responses. Participants viewed and rated each video on a 7 point Likert scale (from ‘not at all’ to ‘to a great extent’) on each emotional dimension of disgust, sad, fear, anger, and neutrality (see appendix Participants were not given any specific instructions about what to do during the videos except to watch them closely from beginning to end. From this piloting phase, stimuli were selected that received the highest ratings on the ‘target’ emotion (sadness, disgust, or fear) and had low ratings on the non-target emotions Clips were required to have significantly higher ratings on the target emotion than on at least two of the other dimensions (see Appendix 8 for ratings). This resulted in a set of 12 videos (3 neutral, 3 sad, 3 disgusting, and 3 fearful) to be taken into the next stage of the study.

### 2.2.2 Paradigm development

One of the primary research questions behind this study was the extent to which the neural underpinnings of interpersonal emotion regulation would overlap, or be distinct from, the neural underpinnings of intrapersonal regulation. The paradigm therefore created two conditions that would be identical as far as possible aside from the target of the emotion regulation; being either the ‘self’ (intrapersonal) or ‘other’ (interpersonal). This therefore allowed for a direct comparison to be made between the brain imaging data of each condition, to address the question of to what extent the neural underpinnings differed.

The paradigm involved participants viewing a series of emotion-eliciting video clips. While the clips were onscreen, in the bottom right-hand corner of the screen participants were also able to see a video link to another person. This other person was facing the camera, and it appeared to the participant that this other person was watching the same video clips as the participant, but in another location to the participant.

In both conditions the other person made facial expressions that were congruent with the target emotion that was elicited by the video (e.g., if the video showed a zit being squeezed, then the experimenter looked disgusted). The other person made the emotional expression for the 10 seconds that the video was present on screen. Following the end of each video the overlaid video of the other person remained onscreen for a further five seconds, during which the facial expression would continue to return to neutral (‘successful’ emotion regulation) or continue making the target facial expression (‘unsuccessful’ regulation). The regulation was successful (i.e. changed expression back to neutral) two-thirds of the time (see Figure 2.1).

For both intra- and interpersonal versions of the paradigm the other person’s initial facial expression at the onset of each emotional video was neutral (see first panel of Figure 2.1). Following onset of the video the facial expression then changed gradually to one congruent with the content of the video during the first five seconds (see panel 2 of Figure 2.1). For the next five seconds of the video (and the final five seconds following offset of the video) the facial expression slowly returned to neutral in an apparently successful regulatory attempt (see panel 3 of Figure 2.1). In one-third of trials the expression did not return to neutral but maintained the emotional expression. As the participant spoke during the first 5 seconds (see 2.2.3) following onset of the video, it therefore appeared that the participants’ utterance was causing the regulatory attempt. In other words, the regulatory attempt and the other person’s emotional response were temporally bound together in a manner that promoted a causal interpretation. During some of the videos the other person would occasionally make eye contact with the camera, and make small gestures (e.g., head nodding) towards the camera in order to give the sense that the interaction between the participant and the other person was dynamic. During the production of the video of the other person the person featured in the videos watched the actual videos on a monitor and heard sample regulatory phrases spoken during the time-frame in which the participants would subsequently be doing so. Therefore, the reactions of the person in the videos were matched to the content and time-course of the emotional videos.

Using pre-recorded videos of the other person’s response rather than using an actual live video link ensured that all participants taking part in the experiment saw the same emotional expressions, which would not suffer from the problems of a live link in terms of subtle differences in timing and intensity of the facial expressions. Using a pre-recorded link also avoided the additional potential technical issues associated with setting up the live link on each occasion.



0 s 1 – 10 s 10 – 15 s

Figure 2.1 – Screen shots from the videos of the other person showing initial neutral expression (0 secs) change to emotional expression (1-10 seconds) and return to neutral expression (10-15 secs). In one-third of trials the expression did not return to neutral but maintained the emotional expression. A large number of videos were made of the conspecific making a congruent emotional facial expression and then modifying the expression based on the regulatory instruction. These were filmed using a built-in computer monitor webcam, and featured the conspecific viewable from the shoulders-up. During filming the conspecific was watching the actual videos on the monitor, so the reactions are accurate to the content and time-course of the videos.

A small number of neutral videos were also presented, during which the experimenter maintained a neutral facial expression for the entire 15 seconds. Neutral videos were included for two reasons. First, this would help prevent against habituation effects of viewing a number of emotion-eliciting clips in succession. Second, this would prevent the ongoing anticipation of a negatively valenced stimulus on each trial that may have led to an ongoing self-regulatory strategy being employed throughout the entire experiment rather than on a trial-by-trial basis.

The other person featured in the overlaid videos was not presented as a true “confederate” within the study (i.e. participants were not told that the other person was another naive participant). Instead participants were told that the other person was part of the investigator team, but that they would not have seen the particular videos to be used until the start of the actual experiment. It was decided to set the experiment up in this way so that each participant would have met the experimenter the day prior to the main experiment session, and would therefore be regulating the emotions of someone with whom they had a standardised level of familiarity with, but no close relationship.

In experiments investigating interpersonal interactions such as interpersonal emotion regulation, it is important to establish that the participants are meaningfully engaging with each other. To this end, within this study, the person in the video had met with the participant on the day prior to the scan and conducted the practice session with them. This ensured that each of the participants had the same level of interaction and familiarity with the other person, and also increased the likelihood that participants would be motivated to regulate that person’s emotion.

### 2.2.3 Regulation instructions: Manipulation of inter- versus intra-personal emotion regulation

The key manipulation of this current study was to vary the target of the emotion regulation process from the ‘self’ (intrapersonal) to the ‘other’ (interpersonal). The interpersonal emotion regulation condition therefore required an interaction to be made between the participant and the experimenter on the video link in order to constitute a valid form of interpersonal regulation (Totterdell, *personal communication*). The way in which this interaction occurred was for the participant to speak aloud to the other person, instructing them as to how they should regulate their emotional state.

To ensure that the two versions of the paradigm (intra- and interpersonal) were matched (which was of paramount importance for the fMRI phase of the study in order to permit a direct comparison) the intrapersonal version also required participants to speak aloud a regulation strategy; participants were therefore required to say a short phrase that corresponded to how they were regulating their emotion according to the task instructions (e.g. it’s just a film). In the interpersonal version of the paradigm participants were required to speak during the same timeframe as the intrapersonal condition, but this time had to direct the other person as to how they should regulate their emotions according to the provided instruction. Notably this would mean that the actual content of what was said differed only very slightly, and in some cases not at all (e.g. “it’s just a film”). Participants articulated their strategy during the first five seconds following onset of the video. Participants were instructed that they should not provide any further utterances for the remainder of the time that the video was onscreen.

### 2.2.4 Regulation instructions: Manipulation of emotion regulation strategy

For *reappraisal* trials participants were given a suggested list of three phrases, one of which they should say during the allocated time, directed to either the self or other (“It’s just a film; “It’s not happening to me/you”; “It isn’t as bad as it looks”).

For *suppression* trials participants were given a suggested list of three phrases, one of which they should say during the allocated time, directed to either the self or other (“Just grin and bear it”; “Don’t show how I/ you feel”;“Just keep a straight face”).

For trials during which no regulation process was to be used, participants were also provided with three suggested phrases (“I’ll just keep watching; I’ll see how this makes me feel”; “I’ll watch this carefully”), one of which they should say during the allocated time.

## 

### 2.2.5 Trial procedure

The title of the clip, regulation instruction, and a reminder of the prototypical phrases appeared for five seconds prior to onset of each video clip. Following the offset of the video link after each stimulus, participants answered three questions using a MRI-compatible button box. The first two of these three questions were rated on a Likert scale (how sad/disgusted do you currently feel; how hard did you try to regulate your emotions; how difficult did you find it to regulate your emotions). For the third question participants were asked to verify which suggested phrase had best corresponded to the strategy that they had used for each trial, by moving the onscreen cursor to one of a list of suggested phrases that had been provided.

### 2.2.6 Order of experimental runs

The experiment was split into two runs, with the intrapersonal run always occurring first. This method, as well as being more understandable to participants than interspersing trials, allowed for the plausible scenario that in the subsequent interpersonal run participants should use their experiences from the first half of the experiment to help them regulate the emotion of the conspecific in the second run. Such a design clearly had implications in terms of potential problems for the fMRI study, in that the order of the runs could not be counter balanced. However this design was deemed necessary in order to fully tease apart the intrapersonal and interpersonal processes. Early piloting of the paradigm with an attempt to counterbalance the runs showed that participants were not able to fully engage in the interpersonal regulation process without having gone through the equivalent intrapersonal regulation process to the same stimuli previously.

In the intrapersonal run, participants were not explicitly instructed to ignore the experimenter in the video link, but were told that their task was to control their own emotional experience. Likewise in the interpersonal run participants were not explicitly instructed to ignore the content of the videos or their own emotional responses, but were simply told that their main task was to regulate the emotion of the other person.

## 2.3 Behavioural pilot

A behavioural pilot was conducted prior to the paradigm being taken forward to the fMRI phase of the research in order to establish that the instructions and tasks were understandable to participants and feasible to perform. Additionally the pilot was intended to provide data which would support the efficacy of the film clips to elicit target emotions, but also be amenable to successful regulation using the instructions of reappraisal or suppression.

26 undergraduate psychology students (19 female, age range 18-20) were recruited from the online departmental recruitment system. All gave informed consent to participate and received mandatory course credit as recompense for their time.

### 2.3.1 Results of piloting

### 2.3.2 Feasibility

Debriefing of each participant following their participation revealed that participants were able to follow the instructions and understand the requirements of each task. This was particularly important to establish due to the highly novel nature of the paradigm.

### 2.3.3 Intrapersonal – Felt Emotion

A one-way ANOVA with within-subject factor of regulation type (suppress, reappraise or watch) for the intrapersonal ratings of affective experience revealed a main effect of regulation type (F(2,50 = 12.59, p<.001). Follow-up tests revealed that ratings were significantly higher when viewed under the instruction to ‘watch’ (mean rating = 4.58) compared to reappraisal (mean=4.03, t=4.86 p<.001) and suppression (mean=4.21, t=3.18 p=.004). There was no significant difference between affect ratings in reappraisal and suppression (t=-1.72 p>0.1).

### 2.3.4 Intrapersonal – Effort

A one-way ANOVA with within-subject factor of regulation type (suppress, reappraise or watch) for the intrapersonal effort ratings revealed a main effect of regulation type (F(2,50 = 26.37, p<.001). Follow-up tests revealed that participants reported putting greater effort into regulating their emotion for reappraisal (mean=4.13) compared to watch (mean=2.97, t=-4.71 p<.001) and for suppression (mean=4.37) compared to watch (mean=2.97, t=-5.78, p<.001). Suppression was associated with more effort than reappraisal (t=-2.68 p<.05).

### 2.3.5 Intrapersonal – Difficulty

A one-way ANOVA with within-subject factor of regulation type (suppress, reappraise or watch) for the intrapersonal difficulty ratings revealed a main effect of regulation type (F(2,50 = 11.36, p<.001). Follow-up tests revealed that participants reported finding it more difficult to regulate their emotions during reappraisal (mean=3.74) compared to watch (mean=3.06, t=-3.18, p<.01) and for suppression (mean=3.97) compared to watch (mean=3.06, t=-3.93, p<.001). There was no difference in difficulty ratings between suppression and reappraisal (t=-1.65, p>0.1).

However it also emerged during debriefing that many participants had found the effort and difficulty questions ambiguous in terms of what aspect of the experience they were trying to capture. Specifically, participants reported uncertainty over how to relate to the questions when ‘watching’ the videos and not trying to control their emotions, yet still being asked how much effort and how difficult they found it to control their emotions. It was also found that the fear eliciting videos were less consistent in evoking emotional response than the other two emotion categories (sadness and disgust).

### 2.3.6 Interpersonal – Other person’s Felt Emotion

A one-way ANOVA with within-subject factor of regulation type (suppress, reappraise or watch) for the interpersonal affect ratings revealed a main effect of regulation type (F(2,50) = 9.36, p<.001). Ratings for perceived affect of the other person were significantly higher when the instruction was to tell the other person to ‘watch’ (mean=4.17) compared to suppression (mean=3.83, t=3.31 p=.01) and reappraisal (mean=3.67, t=4.09 p=.001) with no difference between reappraisal and suppression (t=-.29, p=.78).

### 2.3.7 Interpersonal – Effort

A one-way ANOVA revealed a main effect of regulation type (F(2,50) = 31.61, p<.001) for the effort ratings of regulating the other person’s emotion. Follow-up tests revealed that participants reported putting more effort into regulating the emotion of the other person for reappraisal (mean=4.42) compared to watch (mean=2.54, t=-6.13 p<.001) and for suppression (mean=4.17) compared to watch (mean=2.54, t=-6.13 p<.001), with no difference between reappraisal and suppression (t=1.38 p<.2).

### 2.3.8 Interpersonal – Difficulty

A one-way ANOVA with within-subject factor of regulation type (suppress, reappraise or watch) for the interpersonal difficulty ratings revealed a main effect of regulation type (F(2,50) = 6.54, p<.01). The difficulty of regulating the other person’s emotions by suppression was rated as being more difficult (mean=4.35) than watch (mean=3.63, t=-3.42 p=.002) and there was a trend towards reappraisal being more difficult (mean=4.16) than watch (mean=3.63, t=-2.05 p=.052), with no difference between reappraisal and suppression (t=-1.96 p=.15).

### 2.3.9 Changes to fMRI paradigm following piloting

Due to the finding that fear eliciting videos did not robustly elicit emotional responses to the same extent as the other emotion types, it was decided for the fMRI phase of the study that the fear videos would be replaced by additional disgust- and sadness-eliciting videos.

Due to the highly correlated nature and ambiguity reported by participants during debriefing with regard to the questions “how hard did you try to regulate your emotion” and “how difficult did you find it to regulate your emotion” it was decided for the fMRI experiment to amalgamate the two questions into the single question; “how difficult did you find it to follow the instructions”.

### 2.3.10 Authenticity of video link

Approximately 50% of participants who completed the behavioural pilot reported some level of suspicion over whether the video link was live or not. However, due to the fact that it would be easier to create the illusion of the link during the fMRI experiment, it was decided that the video-link would be retained in the same format during the fMRI experiment. The main reason for the notion that the illusion of a live video-link would be easier to elicit in this context was the reduced physical proximity of the experimenter, who would not be present inside the fMRI room. This would remove several confounding factors that participants had reported following piloting that had been the main source of suspicion as to whether the link was live, such as inconsistencies in the lighting and background of the video in comparison to the testing room. In the piloting the experimenter was in the same room as the participants, whereas in the fMRI experiment the experimenter would apparently be in a separate room, therefore meaning that participants would not identify any problems with the lighting or background. Additionally during the piloting phase a number of participants reported that the reaction of the conspecific to the fear-eliciting videos provided doubts over the authenticity of the video link due to their overly-caricatured nature. With the omission of the fear-eliciting videos from the fMRI experiment it was further reasoned that this would increase the likelihood that participants would judge the link to be authentic in the fMRI experiment.

In summary, the pilot phases of the study involved developing a set of emotion-eliciting video clips that would be suitable for use in an fMRI scanner. Ratings from participants in the piloting stage, and ratings from participants within the various stages of the experiment verified that the video clips were able to elicit the target emotional responses.

## 2.4 fMRI study

### 2.4.1 Hypotheses

Several hypotheses were made about the neural underpinnings of intra- and interpersonal emotion regulation. Firstly, it was hypothesized that intrapersonal regulation would result in recruitment of DLPFC, OFC, vmPFC and VLPFC, as well as ACC, when compared to ‘watch’ (i.e. no regulation). This was based largely on previous studies investigating the neural basis of intrapersonal emotion regulation, as described in Chapter 1 of this thesis. It was also hypothesized that intrapersonal regulation would result in less activation of limbic structures involved in representation of emotional experience, specifically the amygdala and insula, in comparison to watch trials. Behaviourally it was hypothesized that reappraisal and suppression would both lead to reductions in self-reported affect in comparison to a ‘watch’ control condition.

In terms of interpersonal emotion regulation, it was hypothesized that various brain areas previously implicated in aspects of social cognition processes would be involved. Specifically it was hypothesized that areas involved in perspective taking and ‘mentalizing’ (TPJ, mPFC, superior temporal sulcus), areas involved in ‘shared representation’ (inferior parietal cortex), and areas involved in making distinctions between ‘self’ and ‘other’ (rostral medial prefrontal cortex, frontopolar cortex, posterior cingulate) would be activated. This was based on the previous literature investigating the neural basis of various aspects of social cognition as discussed in section 2.0 of this chapter.

## 2.5 Materials and Methods

### 2.5.1 Participants

Twenty right-handed volunteers (mean age = 22.65; range 18-30) took part in the study. Participants were recruited from the local student and staff population via email distribution lists. None of the participants had previously participated in the stimulus validation or pilot experiments, or taken part in any previous emotion regulation studies. Handedness was verified by the Edinburgh Handedness Inventory (mean score = 81; Oldfield, 1971). All participants were native English speakers and had normal or corrected-to-normal vision. Written informed consent was obtained from all participants. All participants were compensated £30 following completion of the study. All of the participants were free of any current or history of psychiatric diagnosis or neurological impairment.

### 2.5.2 Pre-scan session

The day before the fMRI session participants came into the lab to meet with the experimenter, provide informed consent, and run through the tasks they would have to perform in the scanner. Participants then saw a small number of example stimuli that were similar in content to the videos used in the experiment. Viewing example videos allowed participants to confirm that they would be happy viewing such stimuli in the scanner environment, and also allowed them to become familiar with the pacing and timescale of the task; this was particularly important given the time window during which they were required to speak was strictly fixed. Participants then went through a series of instructions and example trials that familiarised them with the processes that they would undergo during the scan. Participants were particularly reminded of the need to articulate their chosen regulatory strategy during the first five seconds of the video and not make any further utterances for the remainder of the trial. It was particularly important that participants spoke only during this phase so that in the analysis of the neuroimaging data activations related to preparation of speaking and motor movements related to speaking would be matched across conditions, in that they all occurred during the same time window. If necessary participants were able to repeat the instructions and practice phase until such point where the participant was fully adhering to the instructions and would be able to adhere to the instructions on the day of the scan.

C:\Documents and Settings\ghallam\My Documents\Dropbox\Papers\bEROS\Neuropsychologia_submission\Neuropsychologia_figure2_new\Neuropsychologia_figure1.TIF

Figure 2.2 - Description of paradigm. In both runs, each trial began with the name of the clip and the instruction type (reappraise, suppress or watch). The three example phrases that participants should select from were also displayed. Following the onset of the video, participants spoke aloud their choice of regulatory strategy within the first 5-seconds. At the end of the video, the face of the person watching the videos with them (bottom right-hand corner) remained visible for 5-seconds. Participants then recorded their or the other person’s affect and how difficult (effortful) they found the regulatory process.

## 2.6 Design and Stimuli

The paradigm was identical to the one used for the pilot study, aside from the changes made described in section 2.3.9. In summary, during each scan participants watched a series of sadness- or disgust-inducing videos. The first scan involved participants regulating their own (intrapersonal) emotion whilst the second scan involved regulating another person’s emotions (interpersonal) who appeared via the apparent video-link in the corner of the screen (Figure 2.2). Prior to each video subjects were instructed to either ‘suppress’ or ‘reappraise’ any emotional response, or to ‘watch’ the video without controlling their emotional response. During the first five seconds following the onset of the video participants overtly articulated their emotion regulation strategy. At the end of each video participants reported the intensity of their emotional experience, the difficulty of the task, and confirmed which particular regulation strategy they had used.

Each run (intra- or interpersonal) lasted 14 minutes. This consisted of 21 epochs, each of 40 seconds duration. This comprised three sadness and three disgust eliciting videos, that were viewed under each condition of ‘watch’, ‘reappraise’ or ‘suppress’. In addition three neutral videos were interspersed, which were viewed under the condition of ‘watch’ only. The questions at the end of the neutral trials were identical to those for emotion trials; the first question asked how disgusted/sad did you feel, which in addition to providing a manipulation check that the self-report ratings were being provided accurately by participants (it was expected that the answer to the question for a neutral video would be “not at all”) also served as a check that the emotional material was not compounding over the course of the experiment (which might be indicated if the ratings were higher than expected in response to neutral stimuli). The order of videos was pseudorandomized to ensure that no emotion (sad, disgust or neutral) or regulation type (reappraise, suppress or watch) was presented more than three times in succession. Four counterbalanced versions of the experiment were created to control for order effects within each run; this was particularly important in the context of participants viewing each video on multiple occasions (to reappraise, suppress and watch each video in both intra- and interpersonal contexts).

### 2.6.1 fMRI data acquisition

During each 14 minute functional run, 280 time points were obtained at 3T (Achieva, Philips Medical Systems, Best, NL) comprising 32 x 4mm thick contiguous slices (in-plane resolution 1.797x1.797mm) covering the entire cerebrum and cerebellum. A single-shot, gradient-recalled echo planar imaging (EPI) sequence was used: repetition time = 3 seconds; echo time = 35msecs; FOV=240mm; in-plane matrix = 128x128mm). A high resolution T1-weighted structural scan was also collected from each participant (3D gradient echo, MP-RAGE, TR = 10.5 ms; TE = 4.8 ms; spatial resolution = 0.8mm3) for normalization purposes.

### 2.6.2 fMRI data preprocessing

Scan data were analyzed in SPM 8 (www.fil.ion.ac.uk/spm) implemented in MATLAB 7.1 (Math-works Inc., Sherborn, MA). Images were motion-corrected, spatially normalized to each individual’s high-resolution T1-weighted scan, and smoothed with a Gaussian kernel (full-width half-maximum of 8 mm). Two out of the total 40 functional runs (both runs from the same participant) were discarded due to excessive head motion during the scan (>3mm in any plane). Blood-oxygen-level-dependent (BOLD) response was modeled to an event related wave-form, convolved with a canonical haemodynamic response function and its temporal derivative. Individual’s movement parameters were included as regressors in the final contrast model in order to control for movement artifacts. The contrast of interest focused on the 15-second period during which participants watched the video and performed emotion regulation (or no regulation). At the first individual subject-level, epochs of ‘reappraisal’ and ‘suppression’ were contrasted with ‘watch’ epochs. These first level fixed-effects analyses were taken forward to a second, group-level, flexible factorial design, that allowed examination of main-effects and interactions, with factors of participant, scan (intrapersonal or interpersonal) and regulation strategy (reappraise, watch, or suppress). For the conjunction of the intra- and interpersonal scans (i.e. overall effect of emotion regulation) results are presented at p<0.05 (family-wise error corrected for multiple comparisons). Results for the remaining univariate analyses (main effects on intra- and interpersonal emotion regulation) are presented at p<.001 uncorrected. This main effect statistical threshold was employed given the exploratory and novel nature of these comparisons and is in line with recommendations for such complex and subtle cognitive processes, as used in previous social and affective neuroscience studies (Lieberman & Cunningham, 2009). Co-ordinates for foci of activation were converted from MNI to Talairach by using the ‘mni2tal’ function within MATLAB. This conversion to Talairach co-ordinates allows for a consideration of which Brodmann Areas the activations are found in.

## 2.7 Results

### 2.7.1 Effect of intrapersonal and interpersonal emotion regulation on self-report behavioural ratings

A 3-within scan (regulation strategy: suppression, reappraisal or watch) by 2-between scan (regulation type: intrapersonal or interpersonal) repeated measures ANOVA with self-report behavioural responses as the dependent variable showed a main effect of regulation strategy (F(2,38) = 8.037, p<.01, Fig. 2.3) with emotional experience being higher in the watch condition than in the suppression (p<.05, p<.001 for intra- and interpersonal respectively) and reappraisal (p<.01, p<.001) conditions. For the intrapersonal scans (but not for interpersonal scans), ratings of emotional experience were also significantly higher for suppression than reappraisal trials (p<.05), suggesting suppression was a less effective strategy. There was no main effect of regulation type (intra- vs. inter-personal) on the perceived difficulty of task involved (F(2,38)=.55, p=.58, Fig. 2.3).

C:\Documents and Settings\ghallam\My Documents\Dropbox\Papers\bEROS\Neuropsychologia_submission\neuropsychologia_final_test_fig2.tif

Figure 2.3 - Mean self report affect rating **A.** of the participants (intrapersonal scan) or other person (interpersonal scan). There was a main effect of regulation strategy (F(2, 38)=8.04, p<.01). For intra- and interpersonal scans, reported affect was higher in the watch condition in comparison to both the suppression (p<.05, p<.001 for intra- and interpersonal respectively) and reappraisal (p<.01, p<.001) conditions. For the intrapersonal, ratings were also significantly higher for suppression in comparison to reappraisal trials (p<.05) but not for interpersonal. Ratings for the ‘intra’ conditions refer to the participant’s current affective state, whereas ratings for the ‘inter’ conditions refer to what the participant judged the other person’s affective state to be. **B** There was no main effect of regulation type on the difficulty of following instructions in the interpersonal run (F(2,38)=.55, p=.58), indicating participants adhered to instructions and engaged in the relevant processes

### 2.7.2 fMRI results - Common neurophysiological bases of intrapersonal and interpersonal emotion regulation

Emotion regulation (without differentiating between intra- or inter-strategy or reappraisal or suppression strategy) contrasted with the baseline ‘watch’ trials was associated with activation of left inferior frontal gyrus (IFG: Brodmann’s Area [BA] 45; Talairach and Tournoux co-ordinates [Talairach and Tournoux, 1988]), pre-supplementary motor area (pSMA: BA 6), right DLPFC; BA 46), and left TPJ (BA 39/40, p<0.05 FWE, flexible factorial design) (see Table 2.1).

##### Table 2.1 Areas activated in both tasks (intrapersonal regulation – watch, interpersonal regulation – watch

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Area | Talairaich co-ordinates  X Y Z | | | Voxels | Z-value |
| Lt. IFG (BA 45) | -37 | 18 | 14 | 127 | 6.69 |
|  | *-46* | *17* | *19* |  | 5.51 |
| pSMA/pMPFC (BA 6) | -2 | 13 | 56 | 134 | 6.49 |
| Rt. pSMA (BA 6) (SFG) | 22  *14* | 9  *15* | 57  *58* | 41 | 5.59  5.36 |
|  |  |  |  |  |  |
| Rt. DLPFC (BA 46) | 44 | 34 | 26 | 8 | 5.16 |
| Lt. TPJ | -50 | -51 | 19 | 21 | 5.10 |
| Lt. TPJ | -54 | -50 | 14 | 10 | 5.08 |

Data presented at p<.05 FWE corrected, cluster threshold 5 voxels.

Co-ordinates are shown in standardized neuroanatomical space (Talairach and Tournoux, 1988). BA=Brodmann's area. Lt. =left. Rt. =right. post. =posterior. g. = gyrus. Co-ordinates without a corresponding extent threshold are shown in italics and refer to sub-clusters of the preceding activation

### 2.7.3 Neurophysiological basis of intrapersonal and interpersonal emotion regulation

Intrapersonal regulation (reappraisal and suppression combined) contrasted with watch trials was associated with activation of a number of hypothesized areas; left IFG (BA 45), right DLPFC (middle frontal gyrus; BA 46), and right VLPFC (BA 47). There was also activation of pSMA (BA 6), right supramarginal gyrus/TPJ, left posterior cingulate, left TPJ (BA 39/40), cerebellum, left superior frontal gyrus, and right cuneus/posterior cingulate (BA 23/31) (Figure 2.4).

Interpersonal emotion regulation (reappraisal and suppression combined) contrasted with ‘watch’ trials was associated, in common with intrapersonal emotion regulation, with activation of IFG (BA 45) and pSMA (BA 6), but additionally showed activation within hypothesized areas of rostral mPFC (BA 10), mPFC (BA 8 and 9), left TPJ (BA 39/40) and right temporal pole (BA38). There was also activation within bilateral inferior temporal gyrus (BA 20) and left ACC (BA 9/32) (Flexible factorial design, Table 2.2 and Figure 2.4).

##### Table 2.2. Areas activated in the contrast intrapersonal emotion regulation (reappraisal and suppression combined) > watch

|  |
| --- |
| Area Tal coordinates Voxels z value  X Y Z |
| Lt. Inferior frontal -42 12 16 681 5.75  gyrus (BA 45)  *-44 30 13 4.52*  *-42 6 3 3.76*  Pre-supplementary -2 13 56 824 5.13  motor area (BA 6) *22 11 58 4.83*  *14 15 58 4.57*    Lt. Posterior cingulate gyrus -18 -38 24 61 4.53  Lt. Temporo-parietal junction -48 -44 21 386 4.40  *-48 -53 19 4.35*  *-59 -52 -39 3.78*  Lt. Cerebellum -6 56 -39 138 4.36  / *Peri-acqueductal gray* *6 -45 -36 4.18*  *2 -52 -39 3.89*    Rt. DLPFC 44 36 24 322 4.27  (BA 46) *38 40 18 3.80*  *36 41 9 3.61*    Rt. Insula (BA 13) 42 10 0 128 4.24  Rt. Ventrolateral prefrontal 32 19 -6 62 4.02  cortex (BA 47)  Rt. Temporo-parietal junction 36 -49 32 109 4.23  /supramarginal gyrus  Lt. Superior frontal gyrus -28 40 15 120 4.20  Bilateral. Cuneus /Post. Cingulate 14 -61 18 610 4.14  (BA 23/31) *-8 -68 33 4.03*  *8 -63 31 3.92* |

Data presented at p<.001 (uncorrected) with an extent threshold of 30 voxels

Co-ordinates are shown in standardized neuroanatomical space (Talairach and Tournoux, 1988). BA=Brodmann's area. Lt. =left. Rt. =right. post. =posterior. Co-ordinates in italics without a corresponding extent threshold refer to sub-clusters of the preceding activation

##### Table 2.3. Areas activated in the contrast interpersonal emotion regulation (reappraisal and suppression combined) > watch

|  |
| --- |
| Area Tal coordinates Voxels z value  X Y Z |
|  |
| Lt. Inferior frontal gyrus (BA 45) -38 16 14 109 5.32 |
| Pre-supplementary -4 11 57 163 4.98  motor area (BA 6) |
| Rt. Inferior temporal gyrus (BA 20) 50 -7 -28 58 4.91 |
| *48 -2 -34 3.55* |
| Rostral medial prefrontal cortex 4 59 12 155 4.40 (BA 10) |
| Rt. Superior frontal gyrus (BA 10) 16 59 17 120 3.96 *24 57 14 3.61* |
|  |
| Rt. Medial prefrontal cortex (BA 9) 14 44 18 85 4.36 |
| *16 43 5 4.17* |
| Lt. Anterior cingulate (BA 9/32) -10 38 17 63 4.26 |
| Lt. Inferior temporal gyrus (BA 20) -44 -13 -21 34 4.13 |
| *-44 -18 -16 3.39* |
| Medial frontal gyrus (BA 8) 2 31 39 73 4.08 |
| *4 23 38 3.39* |
| Pulvinar -4 25 14 76 4.03 |
| Lt. Temporo-parietal junction -61 -48 12 156 3.92 |
| *-53 -44 13 3.78* |
| *-58 -45 26 3.72* |
| Rt. Temporal pole (BA 38) 48 15 16 114 3.82 |
| *51 17 -8 3.69* |
| *57 18 1 3.30* |

Data presented at p<.001 (uncorrected) with an extent threshold of 30 voxels.

Co-ordinates are shown in standardized neuroanatomical space (Talairach and Tournoux, 1988). BA=Brodmann's area. Lt. =left. Rt. =right. Post. =posterior. Co-ordinates in italics without a corresponding extent threshold refer to sub-clusters of the preceding activation

### 2.7.4 Comparison of the neurophysiological bases of intrapersonal and interpersonal emotion regulation

The flexible factorial design within SPM allowed for a comparison to be made directly between the intra- and interpersonal scans. The main effect of intrapersonal emotion regulation (i.e. intrapersonal regulation > interpersonal regulation) was examined by adding the contrast weightings ‘1 1’ for the two intrapersonal factors (reappraisal and suppression) and ‘-1 -1’ for the two corresponding interpersonal factors. Brain areas more involved in intrapersonal than interpersonal emotion regulation included hypothesized regions of right ACC (BA 32) and left DLPFC (BA 46). There was also greater activation within bilateral posterior cingulate (BA 31), right insula (BA 13), left precentral gyrus/inferior frontal gyrus (BA 6/9), left mPFC (BA 6), right cerebellum, left superior temporal gyrus (BA 22), and left superior frontal gyrus (Table 2.4).

C:\Documents and Settings\ghallam\My Documents\Dropbox\PhD\PhD chapters\Final draft\new_intra_image.tif

Figure 2.4 - Intrapersonal regulation > interpersonal regulation. Data presented at p<.001 (uncorrected), extent threshold 10 voxels

##### Table 2.4 – Areas activated by the main effect of intrapersonal emotion regulation (intrapersonal emotion regulation – watch > interpersonal emotion regulation - watch)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Area | Tal coordinates  X Y Z | | | Voxels | z value |
|  |  |  |  |  |  |
| Rt. Posterior cingulate  gyrus(BA 31) | 28 | -51 | 19 | 193 | 4.17 |
|  | *26* | *-53* | *36* |  | *3.05* |
|  | *20* | *-56* | *16* |  | *2.63* |
| Lt. Posterior Cingulate gyrus | -18 | -38 | 24 | 35 | 3.63 |
| Peri-acqueductal gray | 4 | -46 | -33 | 75 | 3.45 |
|  | *-2* | *-56* | *-39* |  | *3.29* |
|  | *6* | *-54* | *-33* |  | *2.79* |
| Rt. Anterior Cingulate (BA 32) | 22 | 30 | 19 | 50 | 3.43 |
| Rt. Insula (BA 13) | 44 | 10 | 0 | 33 | 3.40 |
|  | *36* | *8* | *-4* |  | *2.94* |
| Lt. DLPFC (BA 46) | -42 | 30 | 11 | 36 | 3.40 |
|  |  |  |  |  |  |
| Lt. Precentral gyrus (BA 6/9) | -48 | -7 | 24 | 32 | 3.31 |
| Lt. Medial frontal gyrus (BA 6) | -8 | -26 | 53 | 32 | 3.22 |
|  | *-18* | *11* | *58* | *37* | *3.19* |
| Rt. Cerebellum | 30 | -42 | -28 | 79 | 3.18 |
|  | *36* | *-42* | *-21* |  | *2.82* |
| Lt. Superior temporal gyrus (BA 22) | -55 | -10 | 4 | 50 | 3.16 |
|  | *-55* | *-7* | *11* |  | *3.11* |
| Lt. Superior frontal gyrus | -28 | 40 | 15 | 36 | 3.06 |

Data presented at p<.001 (uncorrected) with an extent threshold of 10 voxels

Co-ordinates are shown in standardized neuroanatomical space (Talairach and Tournoux, 1988). BA=Brodmann's area. Lt. =left. Rt. =right. post. =posterior. Co-ordinates in italics without a corresponding extent threshold refer to sub-clusters of the preceding activation

The main effect of interpersonal emotion regulation (i.e. interpersonal regulation > intrapersonal regulation) was examined by adding the contrast weightings ‘-1 -1’ for the two intrapersonal factors (reappraisal and suppression) and ‘1 1’ for the two corresponding interpersonal factors. Areas more activated by the interpersonal emotion regulation task than the intrapersonal task included hypothesized areas of left temporal pole (superior temporal gyrus; BA 38) and rostral mPFC (BA 10). There was also greater activation within bilateral inferior temporal gyrus (BA 20), right posterior insula (BA 13), right cingulate gyrus (BA 31), bilateral caudate, and right cuneus/inferior parietal lobule (BA 7/40) (Flexible factorial design, Table 2.5; Figure 2.5).

C:\Users\eros\Dropbox\Papers\bEROS\Neuropsychologia_submission\Neuropsychologia_figure3.tif

Figure 2.5 – Interpersonal regulation > Intrapersonal regulation, p<.001 uncorrected, extent threshold = 10 voxels.

##### Table 2.5 – Areas activated by the main effect of interpersonal emotion regulation (interpersonal emotion regulation – watch > intrapersonal emotion regulation - watch)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Area | Tal coordinates | | | Voxels | z value |
|  | X | Y | Z |  |  |
|  |  |  |  |  |  |
| Lt. Temporal pole (BA 38) | -34 | 14 | -28 | 34 | 4.30 |
|  |  |  |  |  |  |
| Lt. Pons | -16 | -21 | -28 | 77 | 3.80 |
| Rostral medial prefrontal  cortex (BA 10) | 2 | 59 | 15 | 18 | 3.48 |
|  |  |  |  |  |  |
| Lt. Inferior temporal gyrus (BA 20) | -44 | -13 | -21 | 11 | 3.44 |
|  |  |  |  |  |  |
| Rt. Posterior Insula (BA 13) | 28 | -24 | 21 | 10 | 3.20 |
| Lt. Caudate | -10 | 1 | 15 | 27 | 3.11 |
| Rt. Inferior temporal gyrus (BA 20) | 51 | -7 | -27 | 12 | 3.09 |
| Pons | -2 | -32 | -19 | 20 | 3.07 |
| Rt. Cuneus/Inferior parietal lobule (BA 7/40) | 26 | -44 | 48 | 17 | 2.91 |
|  |  |  |  |  |  |

Data presented at p<.001 (uncorrected) with an extent threshold of 10 voxels

Co-ordinates are shown in standardized neuroanatomical space (Talairach and Tournoux, 1988). BA=Brodmann's area. Lt. =left. Rt. =right. post. =posterior. Co-ordinates in italics without a corresponding extent threshold refer to sub-clusters of the preceding activation

It was also investigated whether the activations observed for the interpersonal regulation condition differed according to the instruction of reappraisal and suppression, on the basis of the previous literature indicating that these strategies may have a differing neural basis for intrapersonal regulation (e.g. Goldin *et al.*, 2008) and within the current data which indicated that reappraisal was more effective at down-regulating emotional experience than suppression as measured by self reported affect ratings.

### 2.7.5 Interpersonal reappraisal

The contrast of interpersonal reappraisal emotion regulation trials contrasted with interpersonal watch trials revealed activation within rostral PFC (BA10), mPFC (BA8), left temporal pole (BA38), and left insula (Table 2.6).

When expanding this contrast to directly compare interpersonal and intrapersonal reappraisal, increased activation was shown in left inferior temporal gyrus (BA20), left temporal pole (BA38), left putamen, rostral mPFC (BA10), left ACC (BA23), and right IPL (Table 2.6).

### 2.7.6 Interpersonal suppression

The contrast of interpersonal suppression emotion regulation trials contrasted with interpersonal watch trials revealed activation within left inferior temporal gyrus/temporal pole, mPFC (BA8), left IFG, right insula (BA13), superior frontal gyrus (BA6), left cingulate gyrus (BA32), and left TPJ (BA40).

When expanding this contrast to directly compare interpersonal and intrapersonal suppression there was significantly more activation for interpersonal suppression in left anterior temporal pole (BA38) and left caudate (Table 2.6).

### 2.7.7 Post scan debriefing

To clarify the experiences of participants during the experiment participants were debriefed following the scans. Participants reported that they were happy that the phrases they had uttered during the interpersonal scan had been used by the conspecific to try and control their emotional responses. No participants spontaneously reported any suspicions that the experimental set-up had not been live.

##### Table 2.6 – Areas activated by interpersonal emotion regulation

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Area | Tal coordinates Voxels Z value  X Y Z | | | | |
| *Interpersonal reappraisal > watch* |  |  |  |  |  |
| Rt. Superior frontal gyrus (BA8) | 14 | 33 | 46 | 13 | 4.07 |
| Medial prefrontal cortex (BA10) | 4  *8*  *8* | 59  *51*  49 | 10  *7*  *14* | 77 | 3.98  *3.63*  3.26 |
| Rt. Caudate | 14 | -24 | 18 | 16 | 3.79 |
| Lt. Putamen | -22 | -4 | 7 | 25 | 3.58 |
| Lt. Temporal Pole (BA38) | -55 | 14 | 3 | 14 | 3.50 |
| Lt. Cuneus (BA7) | -14 | -58 | 53 | 15 | 3.45 |
| Thalamus | 4 | -21 | 3 | 18 | 3.45 |
| Peri-acqueductal grey | 2 | -35 | -3 | 21 | 3.38 |
|  |  |  |  |  |  |
| *Interpersonal suppression > watch* |  |  |  |  |  |
| Lt. Inferior temporal gyrus (BA20) | -50  *-46* | -7  *-9* | -28  *-18* | 31 | 4.77  *3.31* |
| Medial prefrontal cortex (BA8) | 2 | 31 | 39 | 57 | 4.62 |
| Lt. Inferior frontal gyrus (BA45) | -40 | 20 | 14 | 70 | 4.34 |
| Rt. Superior frontal gyrus (BA6) | 18 | 16 | 53 | 29 | 4.29 |
| Rt. Anterior insula (BA13) | 36 | 16 | 0 | 35 | 4.15 |
| Lt. Cingulate gyrus (BA32) | -10 | 21 | 32 | 25 | 4.11 |
| Lt. TPJ (BA40) | -57 | -47 | 24 | 35 | 3.93 |
| Rt. Middle frontal gyrus (BA9) | 34 | 27 | 37 | 41 | 3.81 |
| Medial prefrontal cortex (BA10) | 16 | 43 | 5 | 21 | 3.55 |
| *Interpersonal reappraisal > intrapersonal reappraisal* |  |  |  |  |  |
| Lt. Inferior temporal gyrus (BA20) | -38 | -17 | -21 | 26 | 4.27 |
| Lt. Pons | -8 | -17 | -23 | 21 | 3.90 |
| Lt. Putamen | -24 | -11 | 13 | 31 | 3.88 |
| Lt. Temporal Pole (BA38) | -36 | 10 | -27 | 28 | 3.85 |
| Rt. Caudate | 26 | -22 | 23 | 20 | 3.84 |
| Medial prefrontal cortex (BA10) | 8 | 51 | 7 | 32 | 3.81 |
| Lt. Cingulate gyrus (BA23) | -10 | -14 | 28 | 23 | 3.74 |
| Lt. Superior frontal gyrus (BA9) | -6 | 50 | 23 | 16 | 3.63 |
| Rt. Inferior parietal lobule (BA7) | 30 | -46 | 47 | 25 | 3.56 |
| *Interpersonal suppression > intrapersonal suppression* |  |  |  |  |  |
| Lt. Anterior temporal pole (BA38) | -34 | 16 | -26 | 14 | 4.08 |
| Lt. Inferior temporal gyrus (BA20) | -50 | -7 | -28 | 6 | 3.94 |
| Rt. Lingual gyrus | 20 | -84 | -8 | 8 | 3.50 |
| Lt. Caudate | -8 | 1 | 17 | 13 | 3.43 |

Data presented at p<.001 (uncorrected) with an extent threshold of 10 voxels (\* indicates clusters with an extent threshold of 5 voxels).

Co-ordinates are shown in standardized neuroanatomical space (Talairach and Tournoux, 1988). BA=Brodmann's area. Lt. =left. Rt. =right. post. =posterior. Co-ordinates without a corresponding extent threshold are shown in italics and refer to sub-clusters of the preceding activation

## 2.8 Discussion

The research reported in this chapter investigated the neural correlates of interpersonal emotion regulation; that is emotion regulation where the target of the emotion regulation is another person rather than the self *per se.*

A direct comparison was performed between the regulation of one’s own emotions (intrapersonal emotion regulation) with the regulation of another person's emotions (interpersonal emotion regulation). Both types of regulation recruited areas previously implicated in intrapersonal regulation, including inferior frontal gyrus and pre-supplementary motor area (Oschner & Gross, 2005; Kalisch, 2009), and mentalizing, including left temporo-parietal junction (Gallagher & Frith, 2003). Interpersonal regulation additionally recruited further areas that have been previously implicated in affective simulation and social cognition, including left anterior temporal pole and medial prefrontal cortex (Decety & Lamm, 2007).

### 2.8.1 Imaging data

Both intrapersonal and interpersonal emotion regulation were associated with a largely overlapping network of brain areas, incorporating the bilateral lateral frontal cortices, the pSMA, and left TPJ. Bilateral frontal activation is consistent with the findings of previous studies on the cognitive control of a person’s own emotion (Oschner & Gross, 2005; Kalisch 2009). No hypothesis concerning activation within pSMA had been made for either condition. However, further investigation into the meta-analysis by Kalisch (2009) investigating regulation of negative emotion by reappraisal reported that pSMA was activated across a number of studies of emotion regulation, making it actually one of the most robust findings in the emotion regulation literature. One possible explanation for this finding is that activation within pSMA reflects response inhibition (Hampshire *et al.,* 2010); something that is an inherent part of emotion regulation. It is also possible that, given this area’s involvement in processes surrounding occulomotor control (Grosbas, Laird & Paus, 2005), activation within pSMA reflects the redeployment of attentional resources to non-emotional components of a stimulus (Van Reekum *et al.,* 2007).

Although the involvement of TPJ in the interpersonal condition was hypothesized, given its previously identified critical role in mentalizing (e.g., Gallagher *et al.,* 2000), this area has not been consistently associated with paradigms concerning the control of one’s own emotional experience. A possible explanation for the role of TPJ in the current intrapersonal paradigm is that the current study conceptualized intrapersonal emotion regulation in a more social context; that is, the task involved the control of emotion in the presence of another person, albeit one that the person in the scanner was at the time instructed to ignore. It is possible however that participants had the sense that their emotion regulation was in part motivated (and perhaps being monitored) by the other person, and so processes akin to mentalizing were evoked (i.e. ‘what does the other person think of my regulation attempts?’). This explanation is consistent with the traditional view that the TPJ underpins such mentalizing processes (Gallagher & Frith, 2003). Future studies could investigate this issue more systematically by using paradigms that manipulate whether participants’ attempts to regulate their own emotion occurs in the presence of other individuals; a particularly interesting question given that the majority of ‘real world’ emotion regulation is performed in front of an actual or imagined audience (Erber *et al.,* 1996).

The left DLPFC and ACC were significantly activated in the intrapersonal regulation task when compared directly with the interpersonal condition. This activation within frontal cortex, particularly DLPFC, is in agreement with the existing literature on the cognitive control of emotion (Beauregard *et al.,* 2001; Ochsner *et al.*, 2002; Phan *et al.*, 2005 Eippert *et al.*, 2007; Goldin *et al.*, 2008). This provides further evidence that the recruitment of the frontal cortex, particularly within lateral areas, is crucial in the process of effortful emotion regulation. This includes processes which are intrinsic to the process of emotion regulation, such as response inhibition, working memory, and conflict detection, all of which are underpinned by areas of the frontal cortex responsible for underlying such processes. It should be noted, however, that because the intrapersonal run always preceded the interpersonal run it is possible that greater activation within these two regions for the intrapersonal task may have arisen as a result of this (i.e. their activation is related to the novelty of the stimuli and emotion regulation processes in the intrapersonal run, which may be decreased by the time of the interpersonal run).

Though activation seen in the cuneus/posterior cingulate was not hypothesized for intrapersonal regulation, one plausible interpretation would be the role of this region in self-reflective processing (Lou *et al.,* 2004). Task specific effects seem particularly likely given that the instructions that participants were given asked them to focus on their own rather than the other person’s emotions during the intrapersonal condition. Therefore, the posterior cingulate may reflect the requirement for self-monitoring during the intrapersonal task, whereas in the interpersonal condition there was no requirement to monitor the self. This is also plausible given that participants knew that they would be asked to reflect upon their own emotional state during the questions that followed each trial during the intrapersonal run.

It is interesting to note that the VLPFC, which is implicated in emotion regulation and found in this study, is also commonly found in neuroimaging studies of deception (Spence *et al.,* 2008). Previous research has implicated areas of frontal cortex, particularly the VLPFC, in the withholding of a prepotent response during deception (Spence *et al.,* 2008). Within the present research it is plausible that this area could inhibit the automatic or ‘prepotent’ response of an emotional response in both forms of regulation. Interpersonal emotion regulation in this study might, to some extent, involve deceiving the conspecific about the nature of the stimuli, though the same may also apply for intrapersonal regulation given that one of the reasons that individuals regulate their emotions is in an attempt to deceive other people, or indeed themselves via the processes of self-deception and impression management (Adolphs, 2010; Trivers 2011). Future studies could further investigate this by manipulating whether participants are ‘truthful’ when regulating their (or another person’s) emotion (e.g., using a reappraisal strategy of “it’s just a scene from a movie” though the depicted event is unequivocally real such as a scene from a real-life documentary). Such investigations would be of clinical interest for investigation of disorders where the manner of reappraisal is not realistic or valid, as has been shown to be particularly prevalent in affective disorders (Campbell-Sills & Barlow, 2007).

### 2.8.2 The neurophysiology of interpersonal emotion regulation

Brain areas uniquely involved in interpersonal regulation included the left temporal pole, rostral medial prefrontal cortex, bilateral inferior temporal gyrus, right posterior insula, right cingulate gyrus, bilateral caudate, and right cuneus/inferior parietal lobule. Activation within bilateral inferior temporal gyri for this contrast is consistent with the role that this region plays in empathy (Farrow *et al.,* 2001). Indeed, activation within these areas, and also within the inferior frontal gyrus associated with the regulation of a person’s own emotional state, lends support to the affective simulation account of empathy (Decety & Lamm, 2007). Activation in the inferior frontal gyrus would suggest that regulating another person’s emotion may involve ‘reliving’ the emotional response and modelling the self-regulation process in order to help the other person to control their emotional state.

Activation within the anterior temporal pole during interpersonal emotion regulation is consistent with studies that demonstrate the involvement of these areas in cognitive empathy such as ‘mentalizing’ (Gallagher & Frith, 2003) and the interpretation of another person’s mental state (Jimura *et al.,* 2010). These findings suggest that interpersonal emotion regulation is also underpinned by similar processes to mentalizing, which is consistent with the requirement of the task to take the perspective of the other person to successfully regulate their emotion. Significant activation within the rostral PFC during interpersonal regulation is also consistent with this region’s role in switching between self- and other-perspectives (Burgess, Dumontheil, & Gilbert, 2007). Activation within rostral PFC has also been reported to reflect the emotional synchrony between two individuals (Kuhn *et al.,* 2011), something that participants were likely to be significantly more engaged in during the interpersonal scan than during the intrapersonal scan.

No evidence was found in the interpersonal condition of activation within right inferior parietal cortex or amygdala. This therefore does not support a role of ‘sympathy’ as being crucial for interpersonal emotion regulation. One reason for this might be that sympathy within such a context is likely to be highly contingent upon the individual’s reasons and motivation for regulating the other person’s emotions. Sympathy may well be invoked in the case where the target of the regulation is well known to the person, but may not necessarily be evoked to the same extent when the target of the regulation is less well known to the person.

### 2.8.3 Limitations

One limitation of the current study is that, although speaking out loud to the other person and monitoring the effects of the advice does constitute one form of interpersonal emotion regulation, there are nevertheless many other forms of interpersonal emotion regulation that differ in their manner of implementation and intended effects. For example, Niven, Totterdell & Holman (2009), identified nearly 400 strategies that could be employed in the pursuit of ‘deliberate’ interpersonal emotion regulation.

One reason for the range of different interpersonal emotion regulation strategies might be related to an individual’s reasons for performing interpersonal emotion regulation, which may vary from the entirely selfish to the wholly altruistic. For example, within a relationship an individual may selfishly wish to quickly regulate their partner’s negative emotion to allow them to watch their favourite TV program. It is therefore likely that during a more selfish reason for performing emotion regulation that some of these mechanisms and reasons may not necessarily invoke the mechanisms of empathy to the same extent as seen in this study. Further studies could investigate this by, for example, investigating whether interpersonal emotion regulation of someone better known to the participant (e.g. a close friend) would result in a different pattern of activation. Further studies could also investigate how different strategies for interpersonal regulation might differ in their effectiveness related to whether the person who is the target of the regulation attempt ‘believes’ the content of the regulation attempt (i.e. being told that the event depicted is not real, even when it unequivocally is).

In social cognition experiments investigating interpersonal interactions such as interpersonal emotion regulation, it is important to establish that the participants are meaningfully engaging with each other. To this end, within the current study, the person in the video had met with the participant on the day prior to the scan and conducted the practice session with them. This ensured that each of the participants had the same level of interaction and familiarity with the other person, and also increased the likelihood that participants would be motivated to regulate that person’s emotion, thereby constituting a valid interpersonal emotion regulation task.

Another limitation of study described in this chapter was that the intrapersonal run always preceded the interpersonal run, thereby leaving open the possibility that activations, particularly within the interpersonal scan, may be influenced to some extent by habituation to the stimuli or repetition of the general regulatory processes. Debriefing of participants during piloting of the paradigm prior to the scanning study revealed that it was not possible to counterbalance the order of runs in such a manner that participants were ever able to fully engage in interpersonal regulation without first having engaged in intrapersonal regulation. However due to this limitation the interpretations from this study should be treated with some caution. Future studies that build on this initial study could investigate the nature of interpersonal emotion regulation by focusing exclusively on a more in-depth exploration of interpersonal regulation as opposed to intrapersonal.

It is also important to acknowledge the repetition of the same emotional videos also brings about potential issues in terms of habituation to the stimuli. However given the nuanced nature of the paradigm it was felt that this was necessary within the study. Specifically, the desire was to use the same videos in the interpersonal run as the in the intrapersonal run to put the focus more on the interpersonal regulation aspect rather than further confounding with an intrapersonal regulation process. Essentially, the participant was using their experiences from the intrapersonal run in order to help the other person in the interpersonal run.

It is also important to note that because the study used a number of conditions with a fairly small number of trials within each, the power of the study to detect robust differences between conditions may be limited. Future studies would benefit from reducing the number of different conditions and increase the number of trials within the remaining conditions in order to explore in more detail the potential differences between conditions.

The presence of the other person in the corner of the screen in the intrapersonal task may also have the potential to interfere with the ‘purity’ of the intrapersonal regulation process given that participants may have been monitoring the other person in addition to attempting to regulate their emotion. This is reflected in the data whereby regions associated with social cognition, such as TPJ, were activated, which has not always been observed in other studies investigating intrapersonal emotion regulation (e.g. Phan *et al.,* 2005). However the fact that activation was found within regions previously demonstrated as being involved in intrapersonal regulation (pSMA, DLPFC) and the behavioural data which suggests that intrapersonal emotion regulation was occurring on the relevant trials seems to confirm that this is still a valid intrapersonal emotion regulation task. It is also possible that the presence of the other person in the corner of the screen may have impacted upon attentional deployment in a different fashion in each condition. For example, it is possible that participants directed more attention towards the other person in the interpersonal condition given that their response was a key indicator of the success of the interpersonal emotion regulation attempt. The necessity of setting up the paradigm in this manner was driven by the aim to directly compare between intra- and interpersonal runs. Although not having the other person present in the corner of the screen during the intrapersonal run would undoubtedly have been more consistent with previous paradigms investigating intrapersonal regulation, this would have prevented any direct comparison with the interpersonal run. Future studies could investigate any potential differences more systematically by using paradigms that manipulate whether participants’ attempts to regulate their own emotion occurs in the presence of other individuals or not. This is again particularly interesting question given that the majority of ‘real world’ emotion regulation is performed in front of an actual or imagined audience (Erber *et al.,* 1996).

### 2.8.4 Clinical Implications

The findings may help the understanding of conditions in which both intra- and interpersonal emotion regulatory processes are dysfunctional, such as schizophrenia. The findings suggest that interpersonal emotion regulation is underpinned by brain processes implicated in affective and cognitive components of empathy. This suggests that deficits in these processes, that have previously been observed in disorders such as schizophrenia (e.g., Lee *et al.;* 2004, 2006), may partially manifest as a reduced capacity for interpersonal emotion regulation and hence problems with social interaction. Such an interpretation fits with the idea that schizophrenia can be characterized as a dysfunction of interpersonal functioning (Frith, 1992). Further studies using similar paradigms with clinical groups are required to characterize how specific deficits in interpersonal emotion regulation relate to more general deficits in interpersonal interactions (see chapter 6 for further discussion).

## 2.9 Conclusion

An overlapping pattern of activation was found with an interpersonal and an equivalent intrapersonal emotion regulation task, incorporating a fronto-parietal network. However, as well as the similarities involved in both processes, there were additional activations for interpersonal emotion regulation within regions known to be involved in social cognition and empathy. The overlapping components suggests that Interpersonal emotion regulation therefore appears to share a number of executive processes in common with intrapersonal regulation, but also critically involves systems that may not be required for intrapersonal regulation, such as affective components of empathy.

# Chapter 3 – the neurophysiology of intrapersonal emotion regulation by implementation intentions

**This chapter addresses the research question, identified in Chapter 1, of how strategies for emotion regulation that could be said to be more ‘automatic’ in their nature might differ in terms of their neural underpinnings. This chapter introduces one such strategy that might be considered more ‘automatic’ in the manner by which emotion regulatory effects are achieved, known as ‘implementation intentions’. The process of designing and piloting a paradigm that addresses the research question of what the neural underpinnings of such automatic strategies are is described. An fMRI study that uses this paradigm is then described.**

## 3.1 Implementation intentions

Behavioural research in a variety of fields has shown that goal setting (whether it be an emotion regulation goal or general self-regulatory goal) is not necessarily sufficient for attaining that goal, and also requires goal striving (i.e. deliberate action and resistance to distraction) in order to obtain (e.g. Gollwitzer, 1993). Implementation intentions are a self-regulatory strategy designed to promote goal striving and achieve goal attainment. Implementation intentions link a particular cue, be it intrinsic (e.g. a feeling state) or extrinsic (e.g. a particular type of stimulus encountered) with a specific goal directed behaviour. Implementation intentions take the fairly rigid form of an “if-then” plan in order to achieve this link (e.g. “If I encounter situation x, then I will perform action y!”). This link therefore establishes a commitment to perform the relevant action when a particular cue is encountered that lends itself to goal attainment when that action is enacted.

Implementation intentions first came to prominence in the goal pursuit literature. In terms of promoting goal attainment they have proven effective in a number of areas such as promotion of dieting (Armitage, 2004) and adhering to exercise regimes (Milne, Orbell, & Sheeran, 2002). Implementation intentions have also proven effective at promoting goal striving (a separable component to goal attainment) and shielding such striving from other influences (e.g. Kroese *et al.,* 2011). However the focus of the current research is on more of this ‘one-shot’ behaviour (i.e. regulating emotion to discrete stimuli) therefore this will not be reviewed in detail.

### 3.1.2 Implementation intentions and automaticity

Implementation intentions can also be said to promote goal striving and attainment in such a way that could be considered less ‘effortful’. For example, Webb and Sheeran (2003) showed that a traditionally cognitive resource-depleting task (the colour Stroop task) was less depleting (as indexed by subsequent performance on another cognitively demanding task) when participants had been given a task-related implementation intention strategy before attempting the task, supporting the notion that implementation intentions may be protective against ego-depletion, and can be seen as supporting less effortful goal attainment.

Implementation intentions also support automatization of behaviour given, firstly, the increased salience attributed to the particular trigger that is critical in cueing a subsequent goal directed behaviour (Aarts, Dijkerhuis & Midden, 1999). This relates to the ‘if’ component of an implementation intention plan. Secondly, another mechanism by which the strategy has been said to become automatic is the increased linkage between the cue and the initiation of the behaviour. Such a link makes the goal directed behaviour more immediate in its implementation and more efficient in its implementation by removing the need for deliberation – essentially that the individual knows which particular strategy is to be implemented and does not even need to consider other strategies. (e.g. Parks-Stamm, Gollwitzer & Oettingen, 2007). This relates to the ‘then’ component of an implementation intention plan.

### 3.1.3 Implementation intentions and emotion regulation

The potential for the use of implementation intentions to support emotion regulation is apparent given the constant striving to improve individuals’ ability to regulate, and given the therapeutic potential of strategies shown to improve emotion regulation ability. One of the main issues in emotion regulation is not just the pure ‘ability’ to regulate or capacity to regulate (i.e. executive function), it is knowing exactly when the need to regulate arises, and which particular strategy should be used and how should it be implemented (Webb *et al.,* 2012). The potential for the advantageous aspects of implementation intentions at improving efficiency and cognitive effort required therefore clearly marks them out as having promise at supporting emotion regulation.

Schweiger-Gallo *et al.,* (2009), showed that emotion regulation instructions, when presented in the form of implementation intentions (e.g. “if I see blood then I will remain calm and relaxed!”) were more effective in promoting successful emotion regulation than goal intentions alone in reducing self reported emotional response. The study also showed that such instructions could be effective at helping individuals with specific phobia (in this case arachnophobia) deal with fear elicited by spider stimuli. This study also collected EEG data to show that the effects of such strategies were manifest early in the perceptual process (100ms).

A recent meta-analysis from Webb *et al.,* (2012) also supports the effectiveness of implementation intentions strategies for supporting emotion regulation in comparison to goal intention strategies. This analysis focused on self reported reductions in emotional experience as an outcome measure of emotion regulation success. The claim is therefore not that emotion regulation (or self regulation more generally) supported only by goal intentions is not effective *per se*; numerous studies show the benefit of such emotion regulation strategies (e.g. Ochsner *et al.,* 2002, Webb *et al.,* 2012). However the argument can be made that implementation intentions may achieve the same effectiveness (or even greater effectiveness) but with less physiological ‘effort’ and more efficiency.

### 3.1.4 Goal intentions

Goal intention strategies are strategies for goal attainment that specify a particular performance or desired end state. However crucially such strategies contain some level of ambiguity in the manner by which an individual might achieve those outcomes. The extent to which this ambiguity occurs is variable; when related to emotion regulation it might refer to a desired outcome as vague as ‘try to feel’ less emotion. However other examples might not be quite as vague; instructions used by a number of studies, for example Gross (1998) and a number of studies described in chapter 1 of this thesis, do specify a more specific mechanism of attaining the desired outcome state of feeling less emotional, for example by instructing the individual to take a detached and unemotional perspective. However crucially these instructions still qualify as goal intentions because a strong link is not formed between this particular behaviour and a particular trigger for its initiation (or at least the specificity of the response has not been tied to the environmental trigger).

In summary, although emotion regulation (or self regulation more generally) supported only by goal intentions can be effective, it seems that more automatic strategies such as implementation intentions may achieve the same effectiveness (or even greater effectiveness) but with less physiological ‘effort’ and more efficiency. However despite these differences there has been no previous study using fMRI to investigate the neural underpinnings of emotion regulation that is supported by implementation intentions. Although a demonstration of the neural correlates of implementation intentions supporting emotion regulation would be interesting in its own right, any such investigation in isolation would be limited in terms of how much of an inference could be drawn about how findings may differ from those found for more ‘traditional’ goal intention emotion regulation strategies. It was therefore decided that this investigation would comprise a full comparison directly between goal intention and implementation intentions strategies on an emotion regulation paradigm similar to that used in previous investigations (e.g. Oschner *et al.*, 2002, Banks *et al.*, 2007).

### 3.1.5 Neural basis of automatic emotion regulation

Due to the inherent difficulty in conceptualising automatic emotion regulation (see chapter 1 section 1.11) it is perhaps unsurprising that the neural correlates of automatic emotion regulation have not been comprehensively explored. The majority of work to date has focused on a variety of tasks that have been said to include some aspect of automatic emotion regulation in order to complete. This includes ‘affect labeling’, whereby an appropriate label must be assigned to an image of an emotional face (e.g. labeling an angry face as ‘angry’) which requires the emotional content of the face to be automatically processed and reconciled with an explicit label (Lieberman et al., 2007). Using such paradigms in fMRI have revealed that such processing modulates activity within the amygdala through modulation by right VLPFC and mPFC (Lieberman et al., 2007, Payer et al., 2012).

Phillips and colleagues (2008) have also attempted to develop a framework that describes the processes involved in automatic emotion regulation. Specifically this incorporates aspects of automatic behavioural control (such as avoidance behaviours), which rely on regions such as OFC and sgACC, automatic attentional control (such as affect labelling), involving VLPFC, mPFC and ACC, and automatic cognitive change (such as error monitoring and risk learning), involving ACC and OFC. Philips and colleagues proposed that a feed-forward medial prefrontal system (including OFC sgACC, rostral ACC and mPFC) might therefore be one framework that could support the number of processes required for automatic emotion regulation (Philips, Ladouceur & Drevets, 2008).

### 3.1.6 Hypotheses

The current investigation therefore sought to investigate the neural basis of emotion regulation under implementation intention versus goal intention instructions. Participants were asked to regulate their emotional responses to a series of images designed to elicit feelings of disgust or sadness. Prior to the scan one-half of the participants formed goal intentions to use general, non-specific strategies, while the other half formed a specific implementation intention. It was hypothesized that emotion regulation under implementation intentions would be more effective than goal intentions as indexed by self-reported affect rating. It was furthermore hypothesized that emotion regulation under goal intention instructions would recruit areas of prefrontal cortex, specifically DLPFC, VLPFC, and ACC, which would modulate amygdala activation. In contrast, it was hypothesized that emotion regulation under implementation intention instructions would show a different pattern of prefrontal recruitment, relying on more medial frontal areas, specifically orbitofrontal cortex (OFC) in accordance with Philip’s and colleagues model of automatic emotion regulation (Philips, Ladouceur & Drevets, 2008). It was also hypothesized that the amygdala would show differential activation according to task instructions, given the amygdala’s role in emotional processing and regulation (e.g. Banks *et al*., 2007). Specifically it was hypothesized that if implementation intentions proved to have increased efficacy in supporting emotion regulation, that this would be reflected in lower activity within the amygdala for those participants receiving implementation intention instructions in comparison to those receiving goal intentions instructions. Finally, it was hypothesized that connectivity between the amygdala and frontal cortex would vary as a function of implementation intention versus goal intention instructions. Specifically it was hypothesized that under emotion regulation supported by goal intentions the amygdala would demonstrate enhanced connectivity with regions such as DLPFC, whereas emotion regulation under implementation intention instructions would result in enhanced connectivity of amygdala and more medial prefrontal regions, such as OFC.

Given that emotionally laden images have previously been demonstrated to impact upon physiological arousal (Farrow *et al*., 2012, Caseras *et al*., 2007) and that voluntary emotion regulation to such stimuli has been shown to affect such indices (Driscoll, Tranel & Anderson, 2009), skin conductance response data was also collected during the scan in order to investigate whether the nature of the instruction (goal intention or implementation intention) would impact upon the autonomic response to stimuli. It was hypothesized that if implementation intentions were shown to result in lower affect ratings, then this might be reflected in a lowered skin conductance response.

## 3.2 Scanning paradigm

### 3.2.1 Stimuli

Stimuli used in the study were images selected from the International Affective Picture system (IAPS; Lang & Cuthbert, 1995). The IAPS is a standardised set of images widely used as a reliable method of emotion induction in laboratory situations. Specifically images were selected on their ability to induce the emotions of disgust, sadness, or neutral. Images were principally selected on the normative arousal and valence ratings from the previously extensively tested set (Lang & Cuthbert, 1995). In addition the specificity of each image to elicit disgust or sadness was established on the basis of rating work from Mikels *et al.*, (2005). Disgust and sadness-eliciting images were included in order to not limit the instructions to a single emotion type. Neutral stimuli (rated as low arousal and medium valence in Lang & Cuthbert 1995) were included primarily as a means of providing a buffer against the compound effects of repeated presentations of emotional stimuli. This would also enable a further comparison between the brain areas involved in the representation of emotional experience compared to non-emotional experience. The numbers of the IAPS images used in the study are included in Appendix 5. The disgust-eliciting images had a mean arousal rating = 6.25, mean valence = 2.02, sadness-eliciting images had mean arousal = 5.29, mean valence = 2.55, and neutral images mean arousal = 3.13, mean valence = 2.55.

The paradigm involved the presentation of images for 10 seconds at a time. Throughout the first 6 seconds of this presentation the image slowly ‘loomed’ towards the viewer. The image began at 80% of maximum screen size, and slowly moved towards the viewer to fill the screen at 100% by the end of the ‘looming’ period. The reason for this was twofold. Firstly, the slow looming of the image was designed to increase the saliency of the image, and therefore the regulatory requirements due to the increased ‘impact’ of the image (note how this device is often used in advertising and on television news programmes). This was based on previous work showing that either imagining (Davis, Gross, & Oschner, 2011) or actually increasing the size of an image was effective in increasing its impact (Muhlberger *et al.,* 2008). Behavioural work on a small number of the stimuli indicated that, in comparison to a static full-screen presentation of the image, there was a small (though non-significant) impact of the looming in terms of increased arousal and valence ratings. The second reason was that this method of presentation would, to some extent, prevent the participant regulating their response by simply looking at non-emotional aspects of the stimuli. Work from van Reekum and colleagues (2007) has indicated that this might be a particular strategy underlying reappraisal and may account for the involvement of certain areas of the brain typically observed in such paradigms, such as the pre-SMA.

Each image was preceded by a single word that appeared in the middle of the screen for 3 seconds. This word was either ‘Attend’ or ‘Reappraise/Suppress’. Participants had been instructed that images preceded by the word ‘attend’ should be viewed under the instruction to allow any feelings elicited by the image to occur naturally (based on instructions used by Gross, 1998). Participants had been instructed that for images preceded by the word ‘Reappraise/Suppress’ they should carry out the emotion regulation instructions that they had been taught.

### 3.2.2 Paradigm details

The exact order of events within each trial was as follows. The instruction, either ‘attend’ or ‘reappraise/suppress’ appeared in white text, centered on a black background, for 3 seconds. The word was in large text and easily visible to participants. Following this the image then appeared on the screen and was visible for 10 seconds (for which it grew for the first 6 seconds). Following this 10 seconds the image was removed from the screen and was replaced with white text “How sad/disgusted did you feel while looking at the image”. Underneath the text was a white nine-point Likert scale, with the anchors ‘not at all’ or ‘very much’ at each end. Participants answered this question using a button box, and moved the cursor on the screen to the desired location on the Likert scale. Participants operated the button box by pressing two buttons; one with the index finger and the other with middle finger, to move the cursor left and right. Each button press moved the cursor one point along the scale in the desired direction. This question and the window for responding were presented for 5 seconds. Following offset of the question, participants saw a black screen with a small white central fixation cross, at which they were instructed to look at until the start of the next trial. The overall length of each trial was therefore 19.5 seconds.

Participants viewed a total of 45 stimuli within each block. This comprised 18 disgust-eliciting stimuli (9 viewed under the instruction to regulate and 9 viewed under the instruction to attend), 18 sad eliciting stimuli (9 viewed under instruction to regulate and 9 viewed under the instruction to attend), and 9 neutral stimuli (viewed under the instruction to attend only). It was decided that neutral stimuli would be only viewed under the instruction to ‘attend’ given previous work that identifies the confusion caused to participants when told to ‘regulate’ their response to a neutral stimulus.

Within the block ‘pseudo-blocks’ of regulation type were created whereby participants would be using regulate or attend instruction on 2-4 successive trials. This method was employed in order to increase the ease of using each strategy given the fast-moving nature of the study, although participants were not explicitly instructed that this was to occur. The order of stimuli was pseudo-randomized such that the instruction type (regulate or attend) appeared more than four times in succession. Furthermore no stimulus category (sad or disgust) appeared more than three times in succession.

Different images were also used for the two different blocks (reappraise or suppress), meaning participants saw a total of 90 images over the two runs. The images used in each block were counterbalanced across participants so that each image appeared equal number of times in the reappraise and suppress blocks across participants. The images were also counterbalanced across participants as to whether it was viewed under the instruction to regulate or attend. Additionally for each set of images four different orders of presentation were created to remove the chance that there might be something particular to one particular order or stimuli that might affect the reaction or data of participants.

The order of blocks (reappraise and suppress) was also counter-balanced within both groups (implementation intentions and goal intentions) so that each group had half of its participants performing the reappraisal block first followed by the suppression block, and half of the participants vice versa.

### 3.2.3 Instructions

The key difference between the nature of the instructions received by the two groups was that the implementation intentions group had their goal intention instructions furnished with an implementation intention. Both groups received two sets of the basic instructions, which they were told would take place in two different blocks in the experiment. The basic goal intention instructions for the reappraise block were:

"For some of the pictures you should just watch carefully. Allow yourself to fully experience the feelings that these images naturally produce. These pictures will be preceded by the word 'ATTEND'

For other pictures we would like you to control your feelings. These pictures will be preceded by the word 'REAPPRAISE'. When viewing these pictures, you should adopt a detached and unemotional attitude.";

The instructions for the implementation intentions group built on these instructions by providing the specific plan:

"In addition we would like you to make a specific plan about what you will do when the word REAPPRAISE appears. Tell yourself:

'If I see REAPPRAISE,

then I tell myself these are just pixels on a screen and the picture can't get to me!'

Please repeat this plan to yourself three times. Do not move on until you are sure that you can remember it";

Participants also received instructions about a ‘suppress’ strategy that they would use in the other block within the study. The goal intentions instruction for this comprised:

“For other pictures we would like you to control your feelings. These pictures will be preceded by the word 'SUPPRESS'. When viewing these pictures, you should try to stop yourself from getting emotional. In other words, try to suppress any feelings that you have when looking at the image";

The instructions for the implementation intentions group built on these instructions by providing the specific plan:

"In addition, we would like you to make a specific plan about what you will do when the word SUPPRESS appears. Tell yourself:

'If I see SUPPRESS,

then I block out all bad feelings and just stay cool!'

Please repeat this plan to yourself three times. Do not move on until you are sure that you can remember it";

### 3.2.4 Implementation intentions v goal intentions

Although a demonstration of the neural correlates of implementation intentions supporting emotion regulation would be interesting in its own right, any such investigation in isolation would be limited in terms of how much of an inference could be drawn about how any findings may differ from those found for more ‘traditional’ goal intentions emotion regulation strategies. By using the same paradigm for both groups, that differed only in the nature of the instructions for emotion regulation that were given, the investigation allowed a full comparison to be made between goal intention and implementation intentions strategies.

### 3.2.5. Feasibility of within subjects design

Behavioural piloting revealed that despite the advantages that would be offered by setting up a within-subjects design, whereby participants would regulate emotion in both a goal intention and implementation intention manner, there was no method of setting up such a paradigm in a way that would ensure fidelity of each condition. This was due to the highly specific nature of implementation intentions, that cannot be ‘switched on and off’ at will. A within-subjects design would also lend rise to the possibility that the implementation intention instructions might confer to participants the sense that this strategy was particularly effective, and more effective than goal intentions. Therefore this might call into question any differences in affect ratings between the two conditions.

It was therefore decided that a between subject design would be the optimal design for addressing the research question of interest, whereby each participant would only receive either goal intention or implementation intention instructions for emotion regulation, and would not be aware at the outset of the existence of the other set of instructions.

## 3.3 fMRI study

### 3.3.1 Participants

Forty right-handed healthy participants (20 males; mean age = 20 yr; range 18-23) were recruited from the student population at the University of Sheffield. Exclusion criteria included any psychiatric or neurological disorder or contraindication to MR imaging. All participants spoke English as a first language and had normal or corrected-to-normal vision. Written informed consent was obtained from all participants and the study was approved by the local Research Ethics Committee. Participants were reimbursed £30 for their time.

### 3.3.2 Procedure

### 3.3.3 Pre-scan session

Participants came into the lab in the two day period preceding the scan, where the study was explained in further detail and written informed consent was obtained. Participants then viewed the task instructions on a computer screen (as described in section 3.2.3). They then viewed three example stimuli, not used in the subsequent scanning study, for each instruction in order to practice the tasks and verify they understood the nature of the material they would be viewing. Participants verbally verified that they understood the tasks and what they would be required to do in the scanner. Participants received only one version of the instructions (i.e. either goal intentions or implementation intentions) and were not aware at this stage that there was another condition to which they could have been assigned. This therefore minimized the possibility that participants were under the impression that they were receiving a more or less effective strategy for emotion regulation than other participants (participants were told about the existence of the other condition at the end of the scanning study).

Prior to receiving the instructions participants also filled out a number of questionnaire measures. This was in order to provide a further characterization of the sample, and to ensure that participants in the different conditions were well matched. Participants completed the disgust sensitivity questionnaire revised (Olatunji *et al*., 2007), the Emotion Regulation Questionnaire (Gross & John, 2003) and the Edinburgh Handedness Inventory (Oldfield, 1971).

### 3.3.4 Paradigm

Figure 3.1 summarizes the events comprising each trial. Participants viewed a total of 45 stimuli in each block. The paradigm was the same as that described in section 3.2.2 (p102/103).

***C:\Documents and Settings\ghallam\My Documents\Dropbox\Papers\Imp ints\Current working version\first_neuroimage_submission\impint_new_figure1.tif***

Figure 3.1 – Events comprising each trial.

### 3.3.5 fMRI data acquisition

During each functional run, 293 time points were obtained at 3T (Achieva, Philips Medical Systems, Best, NL) comprising 32 x 4mm thick contiguous slices (in-plane resolution 1.797x1.797mm) covering the entire cerebrum and cerebellum. A single-shot, gradient-recalled echo planar imaging (EPI) sequence was used: repetition time = 3 seconds; echo time = 35 msecs; FOV = 240mm; in-plane matrix = 128x128mm). A high resolution T1-weighted structural scan was also collected from each participant (3D gradient echo, MP-RAGE, TR = 10.5ms; TE = 4.8ms; spatial resolution = 0.8mm3) for normalization purposes.

### 3.3.6 Stimulus presentation

Stimuli were presented to participants by being projected onto a screen that was viewable through a forward-mounted mirror above the head coil. The paradigm was programmed in Presentation v14.4 (Neurobehavioural Systems, Inc) and ran on a Toshiba laptop.

### 3.3.7 fMRI data preprocessing

### 3.3.8 Conventional analyses

fMRI data were analyzed in SPM 8 (www.fil.ion.ac.uk/spm) implemented in MATLAB 7.1 (Mathworks Inc., Sherborn, MA). Images were motion-corrected, spatially normalized to each individual’s high-resolution T1-weighted scan, and smoothed with a Gaussian kernel (full-width half-maximum of 8mm). Each subject contributed two functional runs each. A total of 5 functional runs were excluded on the basis of excessive head motion (this comprised two participants who showed excessive movement in both functional runs. A further participant demonstrated excessive movement in only one of the functional runs, therefore the remaining functional run was included in the flexible factorial design). Blood-oxygen-level-dependant (BOLD) response was modelled to an event related wave-form, convolved with a canonical haemodynamic response function and its temporal derivative. Individual’s movement parameters were included as regressors in the final contrast model in order to control for movement artifacts. The contrast of interest focused on the 13-second period from when participants were first provided with the regulation (or attend instruction) throughout the entire regulation period when the image was onscreen. This was in order to fully capture the regulation period, based on evidence that implementation intentions begin to exert their effects in a rapid fashion following identification of the relevant cue (Schweiger-Gallo *et al.,* 2009). At the first individual subject-level, epochs of ‘regulate’ were contrasted with epochs of ‘watch’. These first-level fixed effects analyses were then taken forward to a second, group-level, flexible factorial design, that allowed examination of main effects and interactions, with factors of participant, scan (reappraise or suppress) and regulation strategy (implementation intention or goal intention).

### 3.3.9 Connectivity analyses

An *apriori* hypothesis had been made that the amygdala would show differential activation according to task instructions (see section 3.1.5), given its known role in emotional processing and regulation (e.g. Banks *et al.*, 2007). An area of left amygdala with the most significant height threshold was identified from the main analyses (goal intention > implementation intention). In order to identify and extract the time course of activation of left amygdala from each individual, an additional analysis was conducted that compared all emotional images, regardless of regulation instruction, against neutral images, in order to identify a robust response within the amygdala for each participant. The search was constrained by a mask of the amygdala as defined by using the WFU Pickatlas toolbox within SPM (Maldjian *et al.*,2003). The maximally activated voxel from this analysis was used as the centre of a 5mm radius sphere from which the first eigenvariate was extracted.

A psychophysiological interaction (PPI) term was produced by multiplying these time course vectors with the paradigm vector (regulate +1, attend -1). This PPI term was then re-entered as a regressor at the first level for each individual as an effect of interest, along with the time course and paradigm vectors as effects of no interest. These first-level images were then taken forward to a second-level flexible factorial model with factors of subject and condition (i.e., suppress and reappraise scan). From this second level contrast it was possible to investigate areas showing enhanced connectivity with the left amygdala under the instruction of ‘regulation’ in comparison to attend. This also allowed for an examination of the differences in this connectivity between the goal intention and implementation intention groups. Due to the comparatively exploratory nature of this analysis results were thresholded at p<.001 (uncorrected), with an extent threshold of 5 voxels.

## 3.4 Skin Conductance Response

During the experiment skin conductance response data was also obtained from each participant. MR-compatible SCR equipment was based on a battery-powered, electrically-isolated, same electrode configuration implementation of a previously published method (Shastri *et al*., 2001). SCRs were sampled at 20 Hz from the medial phalange of the left index and middle fingers, using 8mm diameter Ag / AgCl electrodes. SCR traces (17,580 data points per 14-minute, 39-second scan) were analysed in Ledalab v.3.2.9 (www.ledalab.de/; Benedek and Kaernbach, 2010) using the Continuous Decomposition Analysis method to distinguish the phasic (driver) information from the underlying tonic sudomotor nerve activity. Raw SCR data were smoothed via convolution with a Hann window to reduce error noise and fitted to a bi-exponential Bateman function. Data were optimised by a conjugated gradient descent algorithm to reduce the error between them and the inbuilt SCR model. These processing steps allowed computation of a stimulus-locked ‘integrated skin conductance response’ (ISCR), a time-integration of the continuous phasic activity for each stimulus. This ISCR therefore represents an unbiased and time-sensitive measure of sympathetic activity in response to each stimulus (Benedek and Kaernbach, 2010). For investigating whether implementation intention and goal intention emotion regulation strategies may be associated with different skin conductance response, ISCRs from participants in both groups were averaged across epochs, within-subject, using SPSS v19 (IBM Corp, Armonk, NY).

## 3.5 Results

### 3.5.1 Baseline characteristics of participants

Participants in the goal and implementation intentions groups were well matched for age, handedness, baseline emotional sensitivity and habitual emotion regulation use. Independent sample t-tests showed that there were no significant differences between the groups on any of these measures (P>.05 in all cases, see Table 3.1).

|  |
| --- |
| Mean (S.D) Goal Intentions Implementation Intentions |
| Age in years 20 (1.02) 20 (0.98) |
| Handedness 70.5 (12.24) 71.3 (13.07) |
| Disgust sensitivity 36.1 (15.62) 36.2 (15.47) |
| ERQ reappraisal 30.0 (5.62) 29.1 (7.04) |
| ERQ suppression 18.6 (4.88) 19.8 (3.32) |

Table 3.1. Participants in the goal and implementation intentions groups were well matched for age, handedness, baseline emotional sensitivity and habitual emotion regulation use. Independent sample t-tests showed that there were no significant differences between the groups on any of these measures (P>.05 in all cases).

### 3.5.2 Behavioural results

For the self-report affect ratings obtained during the scan, a 2 x 2 ANOVA with within-subject factor of regulation condition (reappraise, suppress or attend) and between-subject factor of instruction (goal intentions or implementation intentions) revealed a significant main effect of regulation condition (F(1,36)=118.1, p<.0001). Pairwise comparisons showed that affect ratings were lower in both the ‘reappraise’ and ‘suppress’ conditions compared to the attend condition (p<.05 in both cases). A further 2 x 2 ANOVA with within-subject factor of attend condition (attend in reappraise run, and attend in suppress run) and between-subject factor of instruction (goal intentions or implementation intentions) revealed that there was no significant effect of attend condition (F(1,36) = 0.546, p=.47) and no significant interaction with instruction (F(1,36) = 1.6, p=.21). This therefore indicates that the difference in effectiveness of the two strategies is not driven by differences in ratings in the attend condition.

Given the specific hypothesis about the effectiveness of implementation intentions and given that ‘reappraise’ and ‘suppress’ conditions were similarly effective in regulating affect, the differences in affect ratings for the attend versus regulate (i.e., reappraise and suppress) condition by instruction were examined. Findings showed that implementation intentions instructions generated lower affect ratings (mean change = 1.85) compared to goal intention instructions (M = 1.31), t = 1.85, p < .05 (one-tailed, Figure 3.2).

E:\New_figure2_impints.tif

#### Figure 3.2 - Mean change in affect ratings as a function of emotion regulation for the two groups.

### 3.5.3 Neuroimaging data

### 

### 3.5.4 Implementation intentions

For participants who had received goal intention instructions, the contrast of emotion regulation (reappraise and suppress combined) against attend revealed significant activation of right middle frontal gyrus (BA10), right superior temporal gyrus/TPJ (BA39), left precentral gyrus (BA6), left posterior cingulate gyrus, right IPL (BA40) and right IFG (BA47) (see Figure 3.3 and Table 3.2).

##### Table 3.2 – Brain areas activation by implementation intentions

|  |
| --- |
| Area Tal coordinates Voxels z value  X Y Z |
| Reappraise II > attend |
| Rt. Ventral parietal cortex 46 -57 29 144 3.91 |
| (BA39/40) *44 -50 39 3.83* |
| *40 -53 32 3.47* |
| Rt. Inferior frontal g (BA47) 40 34 0 27 3.82 |
| *42 35 -8 3.18* |
| Suppression II > attend |
| Rt. Ventral parietal cortex (BA39) 38 -46 21 71 4.08 |
| Rt. Middle frontal g (BA10/47) 30 42 18 63 4.02 |
| Left Pre central g (BA4) -48 -14 48 131 3.89 |
| *-53 -8 35 3.89* |
| *-38 -18 34 3.55* |
| All II > GI |
| Lt. Precentral g (BA6) -53 -8 35 105 3.66 |
| Lt. Precuneus (BA7) -10 -52 52 44 3.58 |
| Rt. Superior temporal g 38 -48 21 35 3.22  (BA39/22) |
| Lt. Precentral g -38 -20 34 41 3.09 |
| Rt. IPL (BA40) 56 -34 22 55 3.01 |
| *50 -35 29 2.97* |
| *48 -37 42 2.65* |

Data presented at p<.001 (uncorrected) with an extent threshold of 20 voxels.

Co-ordinates are shown in standardized neuroanatomical space (Talairach and Tournoux, 1988). BA=Brodmann's area. Lt. =left. Rt. =right. post. =posterior. g. = gyrus. Co-ordinates in italics refer to sub-clusters of the preceding activation

#### 3.5.5 Differences between reappraisal and suppression implementation intention strategies

When looking at the individual implementation intentions strategies (reappraisal and suppression) it was found that both strategies (when contrasted against attend instruction) showed a very similar pattern of activation (Table 3.2). Implementation intentions designed to prompt reappraisal resulted in activation of right TPJ/IPL (BA40) and right VLPFC (BA 47). Implementation intentions designed to prompt suppression also showed activation of right TPJ (BA39) and right VLPFC (BA10/47). The main difference between the conditions was that activation within left precentral gyrus (BA4) was only evident in the suppression implementation intentions. Given (a) these findings, (b) that both reappraise and suppress implementation intentions showed similar effectiveness at reducing self-reported affect, and (c) the specific focus on the neural underpinnings of emotion regulation using implementation intentions versus goal intentions, the remainder of the analyses combines the reappraisal and suppression conditions.

### 3.5.6 Goal intentions

For participants who had received goal intention instructions, the contrast of emotion regulation (both runs combined) against attend (i.e. no regulation) revealed several brain areas that were more activated during regulation than attend. These included bilateral lateral frontal cortex (MFG; BA8/9), pSMA (BA6), and left superior temporal gyrus/TPJ (BA39) (see Table 3.3).

### 3.5.7 Goal intentions > Implementation intentions

The direct comparison of goal intentions (goal intentions > attend) and implementation intentions (implementation intentions > attend) was performed in order to further decipher the activations unique to each of the processes. This revealed that areas more active in goal intentions regulation compared to implementation intentions regulation included the sgACC (BA25), left amygdala, left superior frontal gyrus (BA8), and left parahippocampal gyrus (BA30) (see Figure 3.4).

##### Table 3.3. Areas activated in the contrast goal intentions > attend (includes only participants who received goal intention instructions).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Area | Tal coordinates | | | Voxels | z value |
|  | X | Y | Z |  |  |
|  |  |  |  |  |  |
| Rt. Middle frontal g (BA8) | 44 | 16 | 40 | 85 | 3.85 |
| Lt. Middle frontal g (BA9) | -44 | 15 | 34 | 22 | 3.57 |
| Lt.Temporo-parietal junction (BA39) | -48 | -57 | 25 | 37 | 3.44 |
|  | *-53* | *-51* | *23* |  | *3.35* |

Data presented at p<.001 (uncorrected) with an extent threshold of 20 voxels.

Co-ordinates are shown in standardized neuroanatomical space (Talairach and Tournoux, 1988). BA=Brodmann's area. Lt. =left. Rt. =right. post. =posterior. g. = gyrus. Co-ordinates in italics without a corresponding extent threshold refer to sub-clusters of the preceding activation

### 3.5.8 Implementation intentions > goal intentions

The inverse comparison to 3.5.7 revealed several areas more active in implementation intentions when compared to goal intentions. These included the left precentral gyrus (BA6; -54 -10 38), precuneus (-10 -56 54), right superior temporal gyrus (BA39/22; 38 -50 20), and the right IPL (BA40; 56 -36 22) (see Table 3.4).

C:\Users\Glyn\Desktop\Dropbox\Papers\Imp ints\Current working version\first_neuroimage_submission\Imp ints new figure 3.tif

Figure 3.3 – Brain areas more involved in emotion regulation by implementation intentions in comparison to attending to images. Data presented at p<.001 uncorrected, extent threshold 30 voxels.

C:\Users\Glyn\Desktop\Dropbox\Papers\Imp ints\Current working version\first_neuroimage_submission\Imp_ints_new_figure4.tifFigure 3.4 – Brain areas showing greater activation for emotion regulation by goal intentions compared to emotion regulation by implementation intentions. Data presented at p<.001 uncorrected, extent threshold 30 voxels.

##### Table 3.4. Areas activated in the contrast implementation intentions (> attend) > goal intentions (>attend).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Area | Tal coordinates | | | Voxels | z value |
|  | X | Y | Z |  |  |
| Lt. Precentral g (BA6) | -53 | -8 | 35 | 105 | 3.66 |
| Lt. Precuneus (BA7) | -10 | -52 | 52 | 44 | 3.58 |
| Rt. Superior temporal g (BA39/22) | 38 | -48 | 21 | 35 | 3.22 |
| Lt. Precentral g | -38 | -20 | 34 | 41 | 3.09 |
| Rt. IPL (BA40) | 56 | 22 | 34 | 55 | 3.01 |
|  | *50* | *-35* | *29* |  | *2.97* |
|  | *48* | *-37* | *42* |  | *2.65* |

Data presented at p<.001 (uncorrected) with an extent threshold of 20 voxels.

Co-ordinates are shown in standardized neuroanatomical space (Talairach and Tournoux, 1988). BA=Brodmann's area. Lt. =left. Rt. =right. post. =posterior. g. = gyrus. Co-ordinates in italics without a corresponding extent threshold refer to sub-clusters of the preceding activation

### 3.5.9 Correlation with behavioural data

The nature of the amygdala response during emotion regulation was further investigated by correlating the signal change within the amygdala with the affect ratings obtained during the scan. A region of interest analysis was performed using the MarsBaR toolbox within SPM whereby mean signal change was extracted from the left amygdala for each participant. Mean signal change within the amygdala during emotion regulation compared to attend was extracted. A mask of the left amygdala was created using the WFU PickAtlas toolbox. The mean signal change for each participant was then correlated with their mean reduction in affect (i.e. the mean affect score during emotion regulation subtracted from mean affect score during attend). This analysis showed that the magnitude of reduction in left amygdala during emotion regulation (as compared to attend) was negatively correlated with the reduction in self report affect rating during regulation. Essentially, the signal reduction from amygdala was larger for more ‘successful’ emotion regulation (see Figure 3.5).

C:\Users\gph100\Dropbox\PhD\Minor corrections\PHD_newcorrelation.tif

Figure 3.5 – Correlation between the reduction in amygdala signal as a function of emotion regulation and the reduction in self report affect rating as a function of emotion regulation.

## 3.6 Connectivity analyses

### 3.6.1 Goal intentions

Brain areas that showed increased functional connectivity with the left amygdala during regulation compared with attend in the goal intentions group included the bilateral middle/superior frontal gyrus (BA8), ACC (BA24), and left putamen (see Table 3.5).

### 3.6.2 Implementation intentions

Brain areas that showed increased functional connectivity with the left amygdala during regulation compared with attending in the implementation intentions group included right parahippocampal gyrus (BA38) and the OFC (BA11) (see Table 3.6).

### 3.6.3 Goal intentions > implementation intentions

When directly comparing the results of the PPI analysis of goal intentions and implementation intentions, areas of the brain that demonstrated greater connectivity with the left amygdala during emotion regulation in the goal intentions group compared to the implementation intentions group included the right middle frontal gyrus (BA 6), right pre-central gyrus, right caudate, left ACC (BA32), right lingual gyrus (BA18), left parahippocampal gyrus (BA 19), and left pulvinar.

### 3.6.4 Implementation intentions > goal intentions

Brain areas that demonstrated greater connectivity with the left amygdala during emotion regulation in the implementation intentions group compared to the goal intentions group included the right parahippocampal gyrus (BA35) and left posterior insula (BA13).

## 3.7 Skin Conductance Response

Across all participants there was a robust ISCR identified in response to the emotion-eliciting images (mean ISCR = 1.047). A 2 x 2 repeated measures ANOVA revealed that for ISCR there was no significant main effect of instruction type (goal intention or implementation intention) or condition (regulate or attend) (F(1,24) = .001, p=.971) and no interaction (F(1,24)=1.53, p=.228).

##### Table 3.5. Areas demonstrating enhanced connectivity with the left amygdala under the condition of emotion regulation by goal intention than under attend (includes only participants who received goal intention instructions).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Area | Tal coordinates  X Y Z | | | Voxels | z value |
| Lt. Medial frontal g (BA8) | -10 | 39 | 37 | 72 | 3.82 |
| Rt. Cingulate g (BA32) | 24 | 13 | 32 | 95 | 3.56 |
|  | *25* | *19* | *40* |  | *2.90* |
| Lt. Anterior Cingulate | -8 | 45 | 3 | 45 | 3.42 |
| Lt. Middle frontal g (BA6) | 4 | -26 | 37 | 71 | 3.40 |
| Rt. Superior frontal g (BA8) | 17 | 32 | 50 | 9 | 3.04 |
| Lt. Superior frontal g (BA8) | -24 | 22 | 50 | 21 | 2.99 |
| Lt. Putamen | -30 | -15 | 10 | 25 | 2.94 |

Data presented at p<.005 (uncorrected) with an extent threshold of 5 voxels.

Co-ordinates are shown in standardized neuroanatomical space (Talairach and Tournoux, 1988). BA=Brodmann's area. Lt. =left. Rt. =right. post. =posterior. g. = gyrus. Co-ordinates in italics without a corresponding extent threshold refer to sub-clusters of the preceding activation

Table 3.6. Areas demonstrating enhanced connectivity with the left amygdala under the condition of emotion regulation by implementation intention than under attend (includes only participants who received goal intention instructions).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Area | Tal coordinates  X Y Z | | | Voxels | z value |
| Rt. Parahippocampal g (BA36) | 32 | -26 | -24 | 30 | 3.4 |
| Rt. Orbitofrontal cortex (BA11) | 4 | 11 | 21 | 9 | 3.12 |

Data presented at p<.005 (uncorrected) with an extent threshold of 5 voxels.

Co-ordinates are shown in standardized neuroanatomical space (Talairach and Tournoux, 1988). BA=Brodmann's area. Lt. =left. Rt. =right. post. =posterior. g. = gyrus. Co-ordinates in italics without a corresponding extent threshold refer to sub-clusters of the preceding activation

## 3.8 Discussion

This study is the first to use fMRI to investigate the neural basis of emotion regulation supported by implementation intentions. It was found that implementation intentions were underpinned by overlapping and distinct activations to goal intention strategies, and also demonstrated divergent self-report responses. Increased efficacy of implementation intentions for emotion regulation was shown by the self-report data, whereby larger reductions in affect in comparison to the equivalent ‘attend’ instruction were found for the implementation intention instruction in comparison to the goal intention instruction. This self report finding is also supported by the neuroimaging data, which showed that activity in the amygdala was higher during regulation for the goal intentions group than for the implementation intentions groups, indicating that regulation of emotion was less effective in the goal intentions than implementation intentions.

This study used fMRI to investigate the neural basis of emotion regulation strategies which varied in their inherent automaticity, by whether participants were instructed to use a general ‘goal intention’ or a more specific ‘implementation intention’ strategy. Behavioural and fMRI activation results supported to varying extents the overarching hypothesis that implementation intentions are more effective (lower self-report affect ratings), and exert their influence via increased modulation of the amygdala.

The lower self-report affect ratings for the implementation intentions group compared to goal intentions are in agreement with previous studies suggesting that forming specific if-then plans in the form of implementation intentions is an effective and efficient way to regulate affect (Schweiger Gallo *et al*., 2009; Webb *et al*., 2012).

The increased efficacy of the implementation intention instructions (relative to goal intention instructions) was also supported by the neuroimaging data, which showed that activity in the amygdala was higher during emotion regulation under goal intention instructions than during emotion regulation under implementation intentions. The general role of the amygdala in emotion regulation was further supported by the significant correlation between the reduction in amygdala signal during emotion regulation and the reduction in affect rating, indicating that higher activity within the amygdala is associated with less successful emotion regulation (Wager *et al.,* 2008).

In line with previous studies of more voluntary, effortful emotion regulation (e.g. Ochsner *et al*., 2002, Goldin *et al.*, 2008, Kalisch, 2009) it was found that goal intention instructions activated bilateral DLPFC and left TPJ. These data are consistent with models of voluntary emotion regulation as involving ‘executive control’ systems within the brain related to effortful processes. Indeed, recent findings support the idea that regions such as the left DLPFC are involved in more general effortful executive processing rather than being specific to emotion regulation (Golkar *et al.*, 2012). In contrast, emotion regulation under implementation intention instructions did not show the same pattern of prefrontal recruitment as emotion regulation under goal intention instructions, but instead was associated with a right lateralised fronto-parietal network, as well as activation within the left precentral gyrus. This provides evidence that emotion regulation guided by implementation intentions is dissociable from emotion regulation guided by goal intentions to the extent that different neural systems appear to be recruited.

The hypothesis that amygdala-frontal connectivity would be evident during emotion regulation under goal intention instructions was confirmed and is consistent with a number of previous investigations (e.g. Banks *et al*., 2007, Johnstone *et al.*, 2007) that also demonstrated amygdala-frontal coupling during emotion regulation under goal intention instructions. The current data therefore provide further support for a model in which the efficacy of voluntary emotion regulation is driven by top-down modulation of the amygdala by frontal regions, particularly those involved in cognitive control. No such effect was found for emotion regulation under implementation intentions instructions. Instead connectivity during emotion regulation was found between amygdala and perirhinal cortex/parahippocampal gyrus, and the OFC. Connectivity between the left amygdala and the OFC during emotion regulation under implementation intentions instructions is noteworthy given the orbitofrontal cortex’s posited role in automatic emotion regulation (Phillips, Ladoucer & Drevets, 2007). The current data, therefore, suggest that some of the effects of emotion regulation supported by implementation intentions may be achieved through down-regulation of amygdala activity by the OFC. Other research has also suggested that connectivity between OFC and amygdala is associated with dispositional emotion regulation style (Fulwiler, King, & Zhang, 2012) and that changes in this OFC-amygdala coupling may be a marker for risk of psychiatric diseases such as bipolar disorder (Versace *et al*., 2010).

It is also noteworthy that activation of the sgACC (BA25) was found for the contrast of goal intentions > implementation intentions, given that this region has previously been associated with voluntary emotion regulation (e.g. Banks *et al.,* 2007), and has also been proposed as a general mediator of emotion regulation in the absence of specific instructions towards a particular strategy (Nili *et al.*, 2010). This might therefore be a plausible explanation of why activation in this region was greater for the goal intentions group, which are typified by a relative lack of specific instructions towards a particular strategy, in comparison to implementation intentions which are highly specific in their nature.

The pattern of increased activity within right inferior frontal gyrus (rIFG) and right ventro-parietal cortex (VPC) for implementation intentions is strikingly similar to that observed during paradigms investigating attentional control (Hampshire *et al.*, 2010). Hampshire and colleagues report that rIFG and right VPC are part of a network engaged by cues triggering a particular task-relevant behaviour. An interpretation of the current finding, consistent with Hampshire and colleagues’ data, might therefore be that activation within such areas reflects a rapid orienting of attention that is captured by the relevant cue word appearing onscreen. This pattern of rIFG and rVPC activation was not seen in participants regulating their emotions under goal intention instructions, lending support to the idea that implementation intention instructions may alter the salience of the cue word (Aarts, Dijksterhuis, & Midden, 1999; Webb & Sheeran, 2004; 2007; 2008). This specific pattern of brain activation for implementation intentions is consistent with behavioural studies which suggest that heightened cue accessibility is one of the putative mechanisms underlying the beneficial effects of forming implementation intentions. For example, Webb & Sheeran (2007) found that implementation intentions increased the accessibility of words representing the specified cue presented on screen during a sequential priming task. They, among others (Gollwitzer & Sheeran, 2006), obtained evidence that the effects of implementation intentions are in part driven by the heightened accessibility of cues specified in the ‘if’ part of the plan.

The automatic nature of emotion regulation under implementation intentions seems to be driven by the increased salience of the cue word (supported by rIFG) that allows efficient retrieval of the goal-directed response (supported by rVPC) that, in turn, facilitates more automatic regulation of the emotional response (in the amygdala) by systems known to be involved in more automatic emotion regulation (e.g., the OFC). It is notable that the present findings and the proposed model are consistent with a large body of cognitive and behavioural research on implementation intentions (e.g., Aarts, Dijksterhuis, & Midden, 1999; Gollwitzer, 1993; 1999; Gollwitzer & Sheeran, 2006; Webb & Sheeran, 2007, 2008).

Activation within the left precentral gyrus for the contrast of implementation intentions greater than attend was not one of the specific hypotheses. However it is possible that this activation reflects the involvement of the left precentral gyrus in the activation of verbal working memory contents (e.g. Henson, Burgess, & Frith, 2000; Gruber & Von Cramon, 2003). Such an explanation would be consistent with the role of right VPC in retrieving previously learnt information for use in working memory (Cabeza, Ciaramelli, and Moscovitch, 2012). The neural substrates of emotion regulation under implementation intentions instructions might therefore be interpreted in these terms to the extent that participants learn a particular piece of information (the if-then plan) which is then brought ‘online’ once the participant encounters the cue for action. Although goal intention instructions also involve the memory of a goal-directed behaviour being invoked upon encountering a cue-word, the fact that this ‘memory’ involves a general strategy rather than a response that is specifically tied to the cue may explain why similar activation is not observed for goal intentions. Previous behavioural work has attempted to distinguish implementation intentions from prospective memory instructions, and has suggested that implementation intentions instructions (but not prospective memory instructions) lead to automatic response initiation (Rummel, Einstein, & Rampey, 2012; McDaniel, Howard & Butler, 2008; McDaniel & Scullin, 2010). Within the current investigation, at least, it seems that implementation intentions do recruit processes involved in the activation of verbal working memory.

Although a reliable skin conductance response to the emotionally-laden stimuli was found, the data suggested no significant difference in ISCR between goal intentions and implementation intentions, for the instruction to attend or regulate. It is possible that the relatively small difference self-reported affect between the goal intentions and implementation intentions groups (and between instruction to regulate and attend) would not be reflected in significant SCR differences. It has previously been shown that there is a significant difference in ISCR between different categories of stimuli (threat vs. harm; Farrow *et al*., 2012), rather than between emotion regulation strategies applied to the same category of stimuli. It is also possible that in this task the skin conductance response may have been influenced, particularly in the implementation intentions group, by the salient cue; the neural data indicates that the cue for action promoted attentional capture, which may also be reflected in the skin conductance response, which is known to exhibit an ‘orienting response’ to salient stimuli (Frith & Allen, 1983, Williams *et al*., 2000).

### 3.8.1 Limitations

One limitation of the current study is that although implementation intentions are one strategy that supports action through automaticity, there are many other methods of automatic emotion regulation that can operate. For example this might include affect labelling (‘putting feelings into words’; Payer *et al.*, 2012) or ignoring emotional information whilst executing another cognitive task, such as in the emotional Stroop task (Whalen *et al.*, 1998).

Another limitation of the current data is that it comprises a group of young adults (mean age = 20), which limits the applicability of the findings to older populations. Further studies are warranted to investigate how age may affect the neural underpinnings of automatic emotion regulation, particularly given the increasing evidence that the mechanisms of emotion regulation change in older populations (e.g. Van Reekum *et al.*, 2011). It may also be possible the nature of automatic emotion regulation changes with continued experience throughout adulthood on the basis of continued usage of such strategies which eventually results in them becoming more automatised (Bargh & Chartrand, 1999). It is also possible that there is less of a need for automaticity in such behaviours as emotion regulation in older adults, based on new research that suggests that self-regulation depletion following effortful control (as required for emotion regulation under goal intentions) may not occur to the same extent in older adults when the full maturation of the frontal cortices is achieved (Dahm *et al.*, 2011).

### 3.8.2 Clinical Relevance

These findings may be of clinical relevance given the high prevalence of emotion regulation deficits in psychiatric illness, and given that implementation intentions have proved effective in improving cognitive performance in people with schizophrenia (Brandstätter, Lengfelder, & Gollwitzer, 2001; Garrett *et al*., 2008) and children with ADHD (Gawrilow, Gollwitzer & Oettingen, 2011), the present findings suggest that implementation intentions interventions also hold promise in helping to treat emotional deficits by promoting more effective and efficient emotion regulation (see further discussion in chapter 6).

## 3.9 Conclusion

The present research demonstrates that emotion regulation supported by implementation intentions results in dissociable neural activations compared to emotion regulation under goal intention instructions. The effect of forming implementation intentions seems to be driven by processes involved in attentional control and may support more efficient regulation of areas such as the amygdala, by areas involved in automatic emotion regulation, such as OFC.

# Chapter 4 – The modulation of intrapersonal emotion regulation by Transcranial Direct Current Stimulation (tDCS)

**This chapter will describe two studies which were conducted in order to investigate whether the capacity for voluntary emotion regulation could be affected by transcranial direct current stimulation (tDCS). These studies were designed to investigate the causal contribution of one particular brain area, the dorsolateral prefrontal cortex (DLPFC), to the process of voluntary emotion regulation. Specifically the two studies looked at how manipulating the activity of the left DLPFC could affect the efficacy of either cognitive reappraisal or expressive suppression of disgust-eliciting stimuli.**

## 4.1 Transcranial Direct Current Stimulation (tDCS)

Transcranial direct current stimulation (tDCS) is a brain-stimulation method that can induce transient changes in activity of cortical neuron populations. The method may be considered to be non-invasive in that it does not require any surgical implantations or injections for it to be delivered, and no part of the equipment other than the electrical current penetrates the skin. However caution should be employed when describing any technique as ‘noninvasive’ if its effects are manifesting as an alteration of neuronal, and perhaps behavioural, function.

The apparatus of tDCS consists of a battery powered generator box, which produces and regulates the current delivered, and two silver chloridated electrodes (see Figure 4.1). One electrode acts as the ‘anode’ (the positive electrode) and the other acts as the ‘cathode’ (the negative electrode). The mechanism of operation is that a very weak electric current flows from the anode to the cathode. When there is a gap between these electrodes (i.e. when they are placed at differential locations on the scalp) the electric current will follow a path from the anode to the cathode to complete the circuit. Although some of this current will follow a path around the cerebrospinal fluid and other underlying anatomical features, some of the current passes through the underlying neural tissue. Computational modelling of the passage of tDCS-induced current have revealed an amount of the tDCS activity (as conceptualised by current density) are localised to cortical areas immediately underneath the electrodes, as well as a substantial amount of the current being found in areas with conductive tissue such as skin, CSF, and muscle. (Wagner *et al.,* 2007, Sadleir *et al.,* 2010).

****

#### Figure 4.1 – tDCS equipment.

Battery powered generator (A), saline solution (B) used to soak the pads (D) containing the silver chloridated electrodes (C)

Previous work, particularly from the animal literature, has identified that anodal and cathodal stimulation have different effects on the underlying neuronal population in areas of stimulation (e.g. Nitsche & Paulus, 2000). The primary mechanism of the transient changes is thought to relate to changes in the firing ‘threshold’ of the neurons. Anodal stimulation lowers this threshold, making that region more likely to become active. Cathodal stimulation has the opposite effect, raising the threshold and therefore inhibiting the neuronal firing of that particular area. It has also been observed that the effect of tDCS on neuronal activity can outlast that of the actual stimulation itself (Priori, 2003). The mechanisms of this longer term change in activity are thought to relate to the more general process of long term potentiation and long term depression (Nitsche *et al.,* 2003). Long term potentiation refers to an increase in ‘connection’ between two neurons as a result of increased firing between them, whereas long term depression operates in the inverse direction.

One way of assessing the effects of tDCS stimulation in humans has been by combining it with transcranial magnetic stimulation (TMS). TMS differs from tDCS in that it directly causes firing or inhibition of neurons. TMS can be applied to the motor cortex and can actually cause muscle contractions due to firing of that area of cortex, a technique known as motor evoked potentials (MEPs). The application of tDCS followed by assessment of MEPs can therefore be used to investigate the specific effects of tDCS on the underlying neuronal population. It has been shown that anodal stimulation for 5 minutes (of the motor cortex) resulted in increased magnitude of MEPs, thus confirming the neuronal excitability of anodal stimulation. Conversely cathodal tDCS reduced the magnitude of MEPs, confirming the general inhibitory nature of cathodal tDCS (Nitsche & Paulus, 2000). Such research has been influential in informing how one might predict, therefore, that the effects of tDCS on a particular area of the brain might manifest in different consequences depending on the polarity of stimulation.

The present research used tDCS as a means of modulating neuronal function rather than TMS for a number of reasons. First, the study built on previous work from Pena-Gomez *et al.,* (2011) who demonstrated that tDCS could be used to facilitate emotion regulation, albeit in a slightly different fashion to the current investigation (a passive viewing task was used). Second, the therapeutic potential of tDCS, particularly related to emotional processing, might be considered greater than TMS. One reason for this is the practicality of tDCS; it could be delivered in a patient’s own surroundings given that the equipment is highly portable. Another reason is that there are fewer contraindications for tDCS than for TMS, and the stimulation is generally very well tolerated. For example, a study by Wirth *et al.,* (2011) had participants provide ratings on a number of lexical dimensions (e.g. pain, itchiness, burning) following tDCS stimulation and found that the mean rating for ‘pain’ on a 5-point scale (where 0 = none, 1 = mild, 2 = moderate, 3 = considerable, 4= strong) was only 0.2, with ‘itchiness’ receiving a mean rating of 1.25. Whilst TMS is also generally well tolerated, it has been known to cause stimulation of the musculature of the face particularly in areas of prefrontal stimulation, and has been associated with subsequent tension headaches (Wassserman, 1998). tDCS is therefore well suited to delivering stimulation to frontal cortex as the electric current does not stimulate the underlying musculature.

### 4.1.1 Pharmacological effects of tDCS

There has recently been an increased interest within the literature in understanding how the pharmacological effect of tDCS might be driving the observable effects on neuronal firing thresholds. Pharmacological evidence supports the role of sodium in driving changes in ion flux that account for changes in membrane potentials under anodal stimulation (Nitsche, 2003). The same study also supports a role of the NMDA (N-Methyl-D-aspartic acid) receptor in longer lasting effects associated with anodal stimulation; NMDA being associated with mechanisms of long term potentiation and depression which are critical processes to neuroplasticity. The effects of tDCS stimulation may also be due to modulation of the activity of the neurotransmitter GABA (gamma-aminobutyric acid). A magnetic resonance spectroscopy study (MRS) by Stagg *et al.*, 2009, showed decreased levels of GABA following anodal stimulation of motor cortex in comparison to sham stimulation. It is known that GABA is an inhibitory neurotransmitter (McCormick, 1989), therefore suggesting one mechanism by which anodal stimulation may be interfering with the underlying neuronal population.

### 4.1.2 Effects of tDCS on haemodynamics

There is also evidence to suggest that tDCS does have an effect on the underlying hemodynamics of the cortex below the electrodes. A near-infrared spectroscopy (NIRS) study revealed that 10 minute anodal stimulation led to an increase in local cerebral blood flow, lasting for a period of 8 minutes following the stimulation period (Merzagora *et al.,* 2010), suggesting an increase in firing of that neuronal population. There was no particular effect of cathodal stimulation on blood flow, which may in part explain why cathodal stimulation has led to less consistent observable changes in cognitive paradigms that have utilised both forms of stimulation.

Recent studies have also demonstrated that tDCS stimulation results in haemodynamic changes that are observable with fMRI. A recent study (Zheng *et al.,* 2011) showed that both anodal and cathodal stimulation led to observable changes in haemodynamic response in a paradigm that investigated tDCS stimulation of motor cortex concurrently with fMRI. Anodal stimulation showed an increased haemodynamic response following stimulation, whereas cathodal stimulation led to an initial small increase in response followed by a decrease in response following offset of stimulation. These data therefore confirm that tDCS can have an effect on the area of stimulation in a polarity dependant fashion.

### 4.1.3 Effect of electrode size

It has been shown that different sized electrodes may result in different effects at the area of stimulation, for example Nitsche e*t al., (*2007) showed that reducing the area of the stimulating electrode results in a more focal delivery of the current, therefore a more precise localization of what exact area of the underlying cortex is stimulated. However smaller electrodes are more likely to suffer from excessive heating, therefore a size of around 1.5-2.5 cm3 is typically used, which provides a balance between focal delivery and does not suffer from excessive heating.

### 4.1.4 Electrode montage

The potential for multiple active electrodes is also beginning to be developed (in a similar set-up to electroencepholography) which would potentially allow for different areas of the brain to be stimulated simultaneously, or possibly even deeper brain structures (Dmochowski *et al.,* 2011). However such methods remain in active development and are yet to be widely employed for research purposes.

## 4.2 tDCS and emotion processing

tDCS has been recently used to investigate the neural basis of emotion processing. One study (Boggio *et al., 2*009) investigated whether stimulation of the lDLPFC would alter participants’ perception of images of humans in painful situations in terms of their pleasantness and emotional discomfort. It was shown that anodal stimulation of lDLPFC, in comparison with sham stimulation and real stimulation of the primary motor cortex, resulted in decreased ratings of the stimuli for their unpleasantness and emotional discomfort. The lack of modulation by the primary motor cortex stimulation showed that the behavioural effects were not simply due to some non-specific mechanism of the tDCS stimulation itself (e.g. increased attention as a result of the sensation of stimulation).

Another study (Hortensius *et al.*, 2012) aimed to investigate whether manipulation of the ‘balance’ of cortical excitability in the frontal cortex would impact on aggression. The study showed that anodal stimulation of lDLPFC, when coupled with cathodal stimulation of rDLFPC (i.e. increasing excitability of lDLPFC and dampening rDLPFC) resulted in increased ‘aggression’ of participants following an anger-induction procedure. However no such effect was found in the opposite direction (i.e. lDLPFC cathodal, rDLPFC anodal). The authors concluded that this finding supported the notion that asymmetry of activation within frontal cortex relates to approach-withdrawal aspects of emotional behaviour. Aggression, being an ‘approach’ behaviour, was said to have occurred due to this increased asymmetry.

### 4.2.1 tDCS and the DLPFC

Studies such as Hortensius *et al.,* (2012) provide a reminder that the contribution of frontal cortex to emotional aspects of behaviour and experience is a complicated picture, and that the role of such regions extends beyond just being specific to emotion regulation. Other studies have also demonstrated a modulatory effect of tDCS on various cognitive tasks. For example, anodal tDCS to the lDLPFC improved performance on a picture naming task (Fertonani *et al*., 2010). The DLFPC has also provided the target of tDCS stimulation designed to manipulate risk-taking behaviour in a gambling task in both young (Fecteau *et al.,* 2007a) and older adults (Fecteau *et al.,* 2007b). Both of these studies found that anodal stimulation over lDLPFC resulted in reduced risk-taking behaviour, suggesting tDCS was effective in facilitating the inhibitory control of the DLPFC over impulsive actions.

Furthermore, tDCS has also been shown to have an influence on planning ability as assessed using a computerized Tower of London task. Delivery of cathodal tDCS in early sessions and anodal tDCS in later sessions was associated with improved performance on the task, demonstrating a specific facilitatory effect on planning ability. One explanation offered by the authors as to the ‘combined’ effect of cathodal and anodal stimulation was that it was the result of decreasing neuronal “noise” with early cathodal tDCS, with subsequent excitability increases of anodal tDCS in the later stages enhancing efficacy of connections (Dockery *et al.,* 2009).

## 4.3 tDCS and emotion regulation

The only previous study to investigate the effects of tDCS specifically on emotion regulation ability is Pena-Gomez *et al.*, (2011). This study investigated whether anodal stimulation of the lDLPFC, given its role in emotion regulation (see chapter 1, section 1.4.2) would result in alterations in the valence ratings of negative, positive and neutral images. The study investigated 16 healthy participants in a sham controlled crossover design. Participants completed two experimental sessions on consecutive days. During each session participants viewed 180 images (60 positive, 60 negative, 60 neutral) from the IAPS (Lang & Cuthbert, 1995). Each image was presented for 3 seconds, after which participants were required to rate the valence of the image on a 9-point scale from ‘negative’ to ‘positive’.

During one of the sessions participants received 20 minutes of anodal stimulation over the lDLPFC and during the other session received sham stimulation (sham stimulation was 30 seconds of stimulation followed by a ramping down of the current; it was necessary to deliver sham in this manner due to the crossover design). Stimulation was commenced 5 minutes before the start of the experimental task and continued for 15 minutes during the experimental task; the task was 25 minutes in length therefore the final 10 minutes of the task was completed in the absence of any stimulation.

It was found that the ratings for positive and neutral pictures were not altered as a function of stimulation type. However it was found that valence ratings for the negative pictures was significantly higher (i.e. more positive) during anodal stimulation compared with sham. A further control experiment using cathodal stimulation over lDLPFC using the same paradigm found no effect. The magnitude of the effect was also found to be inversely correlated with the participant’s level of extroversion, which the authors speculate might be as a result of different levels of resting ‘activity’ within frontal cortex that might make the effect of tDCS variable between participants. This study provides support for the notion that tDCS might be able to demonstrate an effect on emotional processing and informed the current investigation of how tDCS might impact upon ‘voluntary’ emotion regulation.

## 4.4 tDCS and clinical disorders

The ability of tDCS to influence neural activity is also seen as having a potential therapeutic role, particularly in the amelioration of affective disorders, such as major depression. However studies have revealed inconsistent findings on the efficacy of such treatment to date. One study demonstrated a reduction in self-report measures of depression, in comparison to a sham stimulation group, following five day-successive sessions of 20 minutes stimulation over lDLPFC, in 10 patients with major depression (Boggio *et al.,* 2008). Another larger study in 40 patients also demonstrated similar findings that persisted for 30 days following treatment, following 10 successive sessions of 20 minute stimulation (Fregni *et al.,*2006), though another study in a different group of 40 patients, also using 10 sessions, failed to replicate this finding (Loo *et al.*, 2010).

There has also been a recent interest within the field of psychiatry in the potential use of tDCS in the treatment of positive symptoms of schizophrenia, particularly auditory hallucinations. One small study (Brunelin *et al.*, 2012) showed that anodal stimulation of lDLPFC and concurrent cathodal stimulation of left auditory cortex, for 20 minutes on five consecutive days, resulted in a reduction of self-reported hallucinations in the 3-month period following stimulation. Such investigations, therefore, suggest a promising avenue for the use of tDCS in the treatment of various symptoms of psychiatric disorders, though such results must be treated with caution due to the small sample size (Sommer *et al.,* 2012) and further replication of the findings is needed.

The current research, therefore, aimed to expand upon the existing work on tDCS and emotional processing by providing an investigation of whether tDCS stimulation might be used to alter the ability of an individual to engage in voluntary emotion regulation.

This line of enquiry is based on the increasingly well developed knowledge of the neural basis of intrapersonal emotion regulation that provides candidate areas for stimulation that might result in an alteration of the phenomological process (e.g. DLPFC). It is also based on the evidence that tDCS can have a measureable effect of the area of stimulation, as shown from both fMRI and pharmacological studies.

## 4.5 Experimental design

### 4.5.1 Study 1.

**Study 1** aimed to investigate whether tDCS applied to the lDLPFC would facilitate the ability of participants to engage in ‘voluntary’ emotion regulation by the strategy of cognitive reappraisal. The rationale for this was based on the known role of the lDLPFC in cognitive reappraisal (e.g. Goldin *et al.*, 2008; see chapter 1, section 1.4.2). A between-groups design was used whereby participants were randomized to receive either active or sham tDCS. The active condition was further split into two groups, one receiving anodal stimulation and the other cathodal. Each participant completed one run of the experiment following stimulation.

It was hypothesized that the use of cognitive reappraisal, in comparison to attending to images (i.e. no emotion regulation), would result in lower self-reported affect ratings. It was furthermore hypothesized that this reduction in affect ratings would be facilitated in those participants receiving active anodal stimulation in comparison to those receiving sham, based on the rationale that increased activation of DLPFC would facilitate the executive processes supported by the lDLPFC that play a crucial role in emotion regulation by the strategy of cognitive reappraisal.

A further question of interest was whether cathodal stimulation would be disruptive to voluntary emotion regulation attempts. The hypothesis made was therefore that self-reported affect ratings during reappraisal would be more similar to those during attending to images in those participants receiving cathodal stimulation, based on the postulated inhibitory effect of cathodal stimulation (section 4.1.2, Zheng *et al.,* 2011), which might render the executive processes supported by the lDLPFC involved in the process of cognitive reappraisal less effective.

It was furthermore hypothesized that any such changes in affect ratings for either anodal or cathodal stimulation would also be reflected by associated changes in skin conductance response. Specifically it was hypothesized that more effective deployment of the regulatory strategy would be associated with reduced skin conductance arousal. This is based on the known physiological responses to emotional stimuli that are typified by increased physiological arousal, reflected in increased skin conductance response (Ekman *et al.,* 1983, Gross and Levenson, 1997, Rohrmann & Hopp, 2008, van Overveld *et al.,* 2009).

### 4.5.2 Study 1 participants

60 participants (31 male, 29 female, mean age = 21.3, range = 18-35, SD = 2.9) were recruited from the student and staff population at the University of Sheffield. Participants were excluded if they reported any current or history of neurological or psychiatric condition, or any other contraindication to tDCS stimulation. Written informed consent was obtained from participants; the study was approved by the local ethics committee.

### 4.5.3 Neuropsychological measures

Participants completed the revised version of the Disgust Scale (Olatunji *et al.*, 2007), which gives an overall measure of sensitivity to disgust eliciting stimuli and situations, with three subscales indicating specific sensitivity to ‘core’, ‘animal reminder’ and ‘contamination’ disgust. This measure was included to provide evidence as to whether the different groups had the same ‘baseline’ disgust reactivity, given the between-subjects nature of the study, and also to allow for an investigation of how any effect of tDCS stimulation might be mediated by individual differences. Participants also completed the PANAS-X (Positive and Negative Affect Scale; Watson & Clark, 1994) as a measure of state affect. The PANAS-X is a 60-item questionnaire that gives a measure of an individual’s state affect on 11 specific dimensions: fear; sadness; guilt; hostility; shyness; fatigue; surprise; joviality; self-assurance; attentiveness, and serenity, as well as a combined scale of general positive and negative affect (Watson and Clark, 1994). The PANAS-X was administered in order to establish that participants in all groups were in a similar affective state prior to commencing the study.

### 4.5.4 Study 2

**Study 2** aimed to investigate whether tDCS applied to the lDLPFC would facilitate the ability of participants to engage in ‘voluntary’ emotion regulation by the strategy of expressive suppression. A between-groups design was used whereby participants were randomized to receive either active or sham tDCS. The active condition was further split into two groups, one receiving anodal stimulation and the other cathodal. Each participant completed one run of the experiment following stimulation.

It was hypothesized that anodal tDCS would have a facilitatory effect of emotion regulation by expressive suppression, given that lDLPFC has also been implicated in emotion regulation by this strategy (Goldin *et al.,* 2008). However this is less clear than for reappraisal as there have been fewer studies investigating the neural correlates of expressive suppression than reappraisal, and therefore no specific directional hypothesis was made in terms of the anodal/cathodal stimulation.

It was furthermore hypothesized that any such changes in affect ratings would be reflected by associated changes in skin conductance response, whereby more effective implementation of the regulatory strategy (i.e. lower self report affect ratings) would be associated with reduced skin conductance response, a marker of autonomic arousal.

### 4.5.5 Study 2 Participants

Study 2 recruited an additional 60 participants (30 male, 30 female) from the same pool as in study 1. The baseline characteristics of participants from Study 1 and Study 2 are presented in Table 4.1 (p143).

## 4.6 Stimuli

The stimuli used in both studies were designed to invoke the emotional response of disgust. Video stimuli varied in duration from 15-54 seconds, and were obtained from a mix of pre-existing sources (e.g. those developed by Gross, 1998, such as a video of an arm amputation, and those video clips used in chapter 2) and clips obtained from publically available internet resources (e.g. YouTube). Varying length videos were used as the requirements for the study were less stringent than an fMRI study where stricter standardization of length of stimuli is required for research design purposes. Variable length videos would also increase the participant’s attention given the less predictable presentation. A total of 28 disgust eliciting videos were obtained, containing scenes such as surgical procedures, bodily injuries, rotten foods, or consumption of disgusting items. 12 stimuli were also obtained that were not designed to invoke feelings of disgust (i.e. they were ‘neutral’ in content), such as images of scenery. This gave a total of 40 unique stimuli.

After giving informed consent and completing the neuropsychological measures participants underwent three example practice trials (using stimuli not subsequently used in the main experiment) in order to familiarize themselves with the tasks and to give them a chance to verify they were prepared for the nature of the material they would view in the study. Following the practice trials, participants were set-up to receive the relevant form of tDCS stimulation. Participants received anodal, cathodal or sham stimulation over the left DLPFC, with the reference electrode being placed over the vertex. The exact positions for stimulation were obtained for each individual participant by using the EEG 10-20 International system (see Figure 4.2); left DLPFC was defined as position F3, measured as 30% between nasion and inion around the ‘top’ and ‘side’ of the head, then 50% of the distance between these two points. The vertex was defined as position CZ, taken as 50% of the distance between nasion and inion over the ‘top’ of the head. The pads were soaked in 0.9% saline solution in order to facilitate delivery of current and prevent heating effects at the skin. The electrodes were fitted by using Velcro straps, and were positioned so that the centre of each electrode was located over the ‘centre’ of the sites F3 and CZ for each participant.

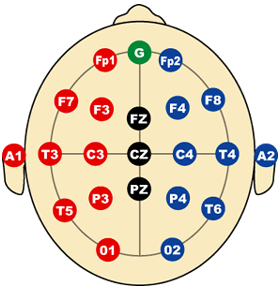


Figure 4.2: EEG 10-20 International System. The red circles correspond to the left hemisphere and the blue circles to the right hemisphere. F3 is the left DLPFC, the site of the “active” tDCS electrode in the current study. Cz is the vertex (image taken from http://www.immrama.org/eeg/electrode.html)

The stimulation commenced immediately prior to the onset of the first video, and continued for 15 minutes of the 40-minute paradigm. This method of stimulation was chosen in order to ensure that the effects of stimulation were present for the duration of the paradigm, whilst at the same time delivering stimulation for a duration (and at an intensity) that was within acceptable and standarised safety parameters (Nitsche *et al.*, 2003). For participants receiving anodal or cathodal stimulation, a current of 1.5mA was delivered by two 5cm x 5cm silver chloride electrodes that were placed within a 1cm thick sponge pad. The stimulation was ‘ramped up’ to the 1.5mA over a period of 30 seconds, with the paradigm commencing once full stimulation intensity had been reached. The experimenter verified verbally with participants that they were not experiencing any excess discomfort before onset of the paradigm. After 15 minutes of stimulation, the current was slowly reduced to zero over the following 30 seconds; participants were not informed that this was taking place and continued with the emotion regulation task (debriefing revealed that almost all of the participants had not noticed the cessation of stimulation). During sham stimulation the set-up procedure was exactly the same as for the active stimulation, differing only in the fact that no current was delivered at all.

Although many previous studies have used 30-seconds of stimulation as a sham condition in order to replicate the initial physical ‘sensation’ of stimulation (e.g. Boggio *et al.,* 2009), the method in this study of no stimulation at all removes any possibility that neuromodulatory effects were present in the sham group. Debriefing revealed that the vast majority of participants were unaware that they had not received active stimulation; this was aided by the fact that none of the participants in either study 1 or 2 had ever received tDCS stimulation before. Additionally the information given to participants prior to the study indicated that there was a large variation in the subjective sensation experienced by different people during tDCS stimulation, and that some people feel very little sensation at all. Many previous studies using the 30-second stimulation sham method have been within-subjects designs whereby participants received more than a single session of tDCS (e.g. Pena-Gomez *et al.,* 2011). As studies 1 and 2 featured only a single session of stimulation with naive participants it was less vital to ensure that the felt stimulation was identical across protocols.

### 4.6.1 Paradigm

The procedure was identical for study 1 and study 2. Participants viewed the 40 stimuli sequentially, stimuli being presented in a pseudo-randomized order. For 14 of the disgust-eliciting videos, whilst the video was visible onscreen participants were required to simply view the clip and permit any emotional responses to occur naturally (the exact instructions were taken from those originally used by Gross (1998) and used for the goal intentions group in the study in chapter 3, see section 3.2.3). For the other 14 disgust-eliciting videos participants were instructed to regulate their emotional responses. This was either by a strategy of cognitive reappraisal (study 1) or expressive suppression (study 2). For participants in study 1, the instructions they were given about how to regulate their emotions using reappraisal were again taken from existing instructions (Gross, 1998, and used in chapter 3, section 3.2.3) and advised them to take a detached and objective perspective to the videos. The suppress instructions (study 2) advised participants to suppress their responses by behaving in such a way that another person watching them would not know how they were feeling (‘expressive suppression’, as per instructions used in Gross, 1998, Goldin *et al.,* 2008).

Participants were cued as to whether they should watch the upcoming video or use an emotion regulation strategy by a word that appeared on the screen for 3 seconds prior to the onset of each video (‘watch’ or ‘reappraise’/’suppress’). Within each study the instruction type associated with each video (‘Reappraise’/’Suppress’or ‘Watch’) was counterbalanced across participants. The order of videos within the paradigm was pseudo-randomized, such that no trial type (*regulate* or *watch*) appeared more than three times in succession. Following the end of each video participants were presented with two questions for 5 seconds each; “how disgusted do you currently feel” and “how difficult did you find it to control your emotion/watch the video”. Participants answered these questions via an onscreen 7-point Likert scale.

### 4.6.2 SCR data collection

During the paradigm skin conductance response (SCR) data was also collected from each participant. This was obtained by taping two silver chloride electrodes to the index and middle finger of the left hand. Onset of the SCR data collection was coordinated with the onset of the paradigm.

## 4.7 SCR Data processing

Data analysis of SCR data was performed in the same manner as described in Chapter 3, section 3.4.

The data from each individual video was averaged over the course of the video to give a single integrated skin conductance response (ISCR) value for each video. This can be taken as a measure of the overall electrodermal activity within a particular window of time.

## 4.8 Behavioural data

Neuropsychological data and behavioural responses obtained during the paradigm were analyzed using SPSS (version 14.0)

## 4.9 Results

### 4.9.1 Baseline characteristics

##### Table 4.1 – baseline characteristics of participants

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Study 1 (reappraise) (N=60) | | | Study 2 (suppress) (N=60) | | |
| Anodal (N=20) | Cathodal (N=20) | Sham (N=20) | Anodal (N=20) | Cathodal (N=20) | Sham (N=20) |
| Mean age (years)  PANAS-X positive  PANAS-X negative  Mean disgust sensitivity | 23  26  12  1.75 | 21  22  14  1.63 | 22  28  13  1.59 | 21  22  12  1.43 | 21  28  12  1.35 | 21  28  13  1.52 |

Table 4.1 shows the baseline characteristics of participants within study 1 (reappraise) and study 2 (suppress). There were no significant differences between groups except that participants in study 1 had significantly higher scores on the DS-R than did participants in study 2 (independent samples t-test, p=.028), indicating that participants in study 1 had a higher sensitivity to disgusting material than did those in study 2. Further examination of the background characteristics reveals that this is likely driven by a higher proportion of participants in study 2 (83%) being medical students compared to participants in study 1 (55%). Comparisons directly between the two studies should therefore be treated with some caution in light of this underlying difference. However it is also worth noting that there were no significant differences on any other of the baseline measures.

There were some differences between participants within each study in terms of the PANAS-X baseline score; participants in the suppress study receiving anodal stimulation had lower baseline positive emotion than those receiving cathodal (p=0.004) and sham (p=0.001). Participants in the reappraisal study receiving cathodal stimulation had lower mean scores on the General Positive Emotion scale compared with those receiving anodal (p=0.036) and sham stimulation (p=0.004). Although the experimenter was not blind to stimulation condition, the participant was only randomized following the neuropsychological measures being filled out so the possibility that the experimenter’s behaviour on the basis of knowing the stimulation protocol could influence the participant’s general state mood is unlikely.

### 4.9.2 Affect ratings

Affect ratings were compared for disgust videos viewed under the instruction ‘watch’ and ‘regulation’. This was in order to investigate the general effect of emotion regulation of affect ratings; this analysis collapsed across all stimulation types.

For study 1 (reappraisal) an independent samples t-test revealed that self reported affect was significantly higher for videos viewed under the ‘watch’ instruction compared with the ‘reappraise’ instruction (t=5.65, df=59, p<.001), indicating that reappraisal was effective in reducing participant’s self-reported emotional experience (see Figure 4.3)

Figure 4.3. Mean affect ratings in the “watch” condition (blue) and “reappraise” condition (green), showing significantly lower affect scores in reappraise compared with watch condition (p<0.001) (bars represent 95% confidence intervals).

For study 2 (suppression) although suppression resulted in lower affect ratings that the watch condition, this effect was not statistically significant (t=1.97, df=59, p=0.117, Figure 4.4).

Figure 4.4: Mean affect ratings and confidence intervals in the “watch” condition (blue) and “suppress” condition (red). There was no significant difference between the two conditions (bars represent 95% confidence intervals).

### 4.9.3 Difficulty ratings

Difficulty ratings were compared for disgust videos viewed under the instruction to ‘watch’ and ‘regulation’. This was in order to investigate the general effect of emotion regulation of difficulty ratings; this analysis collapsed across all stimulation types.

In study 1 (reappraisal) there was no significant difference between difficulty of reappraisal and watch (t=1.131, df=59, p=.304) (Figure 4.5), indicating that participants found following the reappraisal instructions to be equally as difficult as following the watch instructions.

#### Figure 4.5: Mean difficulty ratings and confidence intervals in the “watch” condition (blue) and “reappraise” condition (green).

For study 2, suppression was rated as being significantly more difficult than watch (t=2.16, df=59, p=.042,Figure 4.6).

Figure 4.6: Mean difficulty ratings and confidence intervals in the “watch” condition (blue) and “suppress” condition (red)

### 4.9.4 Effect of tDCS on self-reported affect ratings

In order to combine data from both studies, a difference score was calculated for each participant whereby their affect rating during watch was subtracted from their affect rating during emotion regulation. This difference score was then entered into a 2x3 between-subjects ANOVA of regulation type (reappraise, suppress) and stimulation (anodal, cathodal or sham). This revealed a main effect of regulation type (F(1,114) = 6.90, p<.01) but no effect of stimulation (F(2,114) = .36, p=.70) and no interaction (F(2,114) = .57, p=.57). Paired tests revealed that reappraisal resulted in significantly greater reduction in affect ratings in comparison to suppression (p<.05).

### 4.9.6 Effect of tDCS on self reported affect ratings for study 1 (reappraisal)

Within study 1 (reappraisal), a 3x2 ANOVA of stimulation type (anodal, cathodal or sham), regulation (reappraise or watch) revealed a significant main effect of stimulation type (p<.005), and regulation type (F(1,57) = 31.07, p<.001). There was no significant interaction (F(2,57) = .24, p=.79).

Following up the main effect of stimulation type, pariwise comparison (adjusted for multiple comparisons by Least Significant Difference) revealed that anodal stimulation was associated with significantly lower affect ratings compared to sham stimulation (p=.015), suggesting that participants receiving anodal stimulation were more effectively able to regulate their emotional responses than were the sham group. Anodal stimulation also led to lower affect ratings in comparison to cathodal stimulation though at trend level (p=.099). There was no significant difference between cathodal and sham (Figure 4.7), suggesting cathodal stimulation had no impact on participants’ ability to regulate their emotions. A paired samples t-test also revealed that for participants receiving anodal stimulation, affect ratings for reappraisal (mean = 3.59) were significantly lower than for affect ratings for watch (3.36) (t=2.71, p<.05).

**C:\Documents and Settings\ghallam\My Documents\Dropbox\PhD\PhD chapters\Final draft\tDCS_disgust_r_and_w.tif**

Figure 4.7. Affect rating in response to disgusting videos. Reappraisal was associated with reduced affect ratings relative to watch (p<0.001) across all three conditions of stimulation. Anodal stimulation resulted in reduced affect relative to sham which is significant in the watch (p=0.012) and the reappraise condition (p=0.015).

When looking at the data for the ‘watch’ trials (rather than just the active regulation trials) there was also an effect of stimulation type evident; anodal stimulation led to significantly reduced affect ratings when watching the videos in comparison to sham stimulation (p<.05).

### 4.9.8 Effect of tDCS on self reported affect ratings for study 2 (suppression)

Within study 2 (suppression), a 3x2 ANOVA of stimulation type (anodal, cathodal or sham), regulation (suppress or watch) revealed a significant main effect of stimulation type (F(1,57) = 3.85, p<.05) but no main effect of regulation (F(2,57) = .25, p=.79) and no interaction (F(2,57) = .70, p=.49). Paired tests revealed no significant differences between stimulation conditions, though anodal stimulation was associated with lower affect ratings than cathodal and sham stimulation (Figure 4.8).

C:\Documents and Settings\ghallam\My Documents\Dropbox\PhD\PhD chapters\Final draft\tDCS_disgust_s_and_w.tif

Figure 4.8. Affect rating for study 2 (suppression). Suppression was associated with reduced affect ratings relative to watch (non-significant) across all three conditions of stimulation. Anodal stimulation resulted in reduced affect relative to sham which is significant in the watch (p=0.021) but not the suppress condition.

When looking at the data for the ‘watch’ trials (rather than just the active regulation trials) there was also an effect of stimulation type evident; anodal stimulation led to significantly reduced affect ratings when watching the videos in comparison to sham stimulation (p<.05).

## 4.10 Skin conductance response data

SCR data was collected from 33 participants in study 1 and 40 participants in study 2. SCR data were not collected from all participants due to unavailability of the equipment at the time of data collection.

### 4.10.1 Interaction of tDCS stimulation with ISCR

In order to investigate the interaction of tDCS stimulation with emotion regulation, a difference score between ISCR during watch and ISCR during regulated was calculated. This was then entered into a 2 x 3 between subjects ANOVA with factors of regulation type (reappraise or suppress) and stimulation type (anodal, cathodal or sham).

This revealed a main effect of stimulation type (F(2,67) = 4.103, p<.05) but no effect of regulation type (F(1,67) = 2.173, p=.15) and no interaction (F(2,67) = .81, p=.45). Anodal stimulation led to greater reductions in ISCR during emotion regulation than sham (p<.05) and than cathodal (p<.05) with no difference between cathodal and sham (p=.81).

C:\Documents and Settings\ghallam\My Documents\Dropbox\PhD\PhD chapters\Final draft\tDCS_watch.tif

C:\Documents and Settings\ghallam\My Documents\Dropbox\PhD\PhD chapters\Final draft\tDCS_reapp.tif

C:\Documents and Settings\ghallam\My Documents\Dropbox\PhD\PhD chapters\Final draft\tDCS_supp.tif

Figure 4.9: Mean ISCR by stimulation and regulation type.

### 4.10.4 Correlation of neuropsychological measures with task performance

When correlating the mean affect ratings given by participants in response to the disgusting videos with their baseline disgust sensitivity score, a significant positive correlation was found (R2=0.465, p<0.001; Figure 4.10). This suggests that the disgust sensitivity score was a good predictor of the participant’s responsiveness to the disgusting material encountered in the study and provides a further validation of the content of the emotional stimuli.

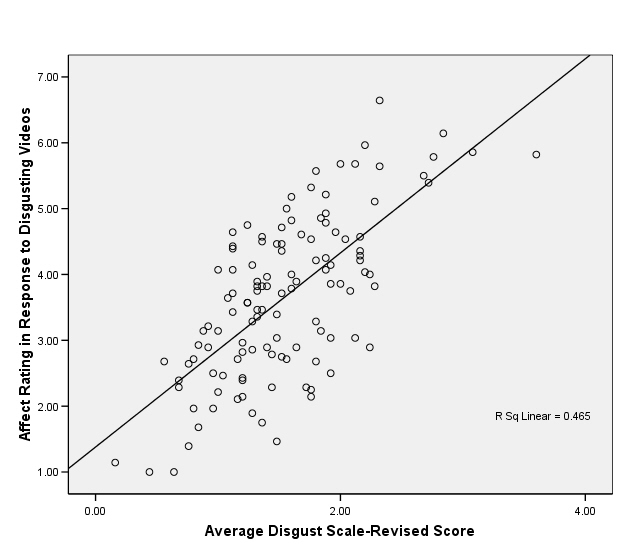


Figure 4.10: Significant positive correlation between average Disgust Scale-Revised score and mean affect rating in response to disgusting videos (across all regulation types, r=0.465, p<.001).

## 4.11 Discussion

Study 1 and study 2 were conducted in order to investigate whether tDCS could be used as a means to affect the ability of an individual to engage in voluntary emotion regulation in response to disgusting material, based on the knowledge of the neuromodulatory properties of tDCS and the neuroanatomical basis of voluntary emotion regulation. The first study investigated whether tDCS would be effective in modulating participants’ ability to engage in cognitive reappraisal, where study 2 investigated the strategy of expressive suppression. The two studies allow for an investigation of whether any effect of tDCS is strategy specific based on the putative role of the target of stimulation in each strategy, or is rather due to a more general non-specific mechanism of stimulation.

In study 1 (reappraisal) anodal tDCS was shown to lead to significantly lower self reported affect ratings than sham stimulation in response to videos viewed under the instruction to reappraise, and also when viewing videos under the instruction to watch. This was also reflected in the peripheral skin conductance response, which showed lower electrodermal activity for the anodal stimulation in comparison to the sham group. In study 2 (expressive suppression), no such effect was found on the self report data or the skin conductance response data.

### 4.11.1 Overall effect of emotion regulation

In both studies the implementation of the relevant emotion regulation strategy led to a reduction in self-reported affect, although this was only statistically significant in study 1 (reappraisal). These findings dovetail with the self-report difficulty rating, whereby implementing emotion regulation strategies was rated as being more difficult than watching the videos, but the difference was larger (and only statistically significant) in study 2. Taken together these findings add support to the relative efficacy of cognitive reappraisal in comparison to expressive suppression (Gross, 1998) and confirms that participants seemed to be engaged in the relevant processes during the study, even in the presence of tDCS stimulation.

Although a direct comparison between ratings in the two studies shows that the affect ratings overall are higher in study 1 (reappraisal), this is most likely driven by the higher baseline disgust sensitivity score in those participants. This is supported by the finding of a positive correlation between DS-R score and both affect and difficulty ratings indicating that participants with a lower DS-R score also demonstrated lower self-report and difficulty affect ratings.

The heterogeneity of the groups means that comparisons directly between study 1 and 2 must be treated with some caution. The primary reason for the differences between the participants within study 1 and 2 is that a higher proportion of participants in study 2 (83%) were medical students compared to participants in study 1 (55%). This was reflected in the fact that participants in study 2 demonstrated lower scores on the disgust sensitivity scale at baseline. This is not surprising given that individuals who undergo medical training will have lower disgust sensitivity due to the nature of their training. Additionally having lower disgust sensitivity may even be a contributing factor towards why such individuals choose to undergo medical training (Consedine, Yu, & Windsor, 2013).

### 4.11.2 tDCS and self report measures

The significant effect of anodal tDCS on self report affect scores in study 1 (reappraisal) supports the hypothesis that anodal stimulation would lead to an improvement in an individual’s capacity to voluntarily regulate emotion by cognitive reappraisal. This supports the role of the lDLPFC in voluntary emotion regulation (e.g. Kalisch, 2009) and is in line with two previous studies investigating the neuromodulatory effect of tDCS over the lDLPFC. The first (Boggio *et al.,* 2009) found that anodal stimulation of DLPFC led to reduced ratings of images of human pain, and the second study (Pena-Gomez *et al.,* 2011) found that anodal tDCS over lDLPFC led to reduced ratings of unpleasant images during passive viewing. It is also perhaps noteworthy, therefore, that the anodal stimulation in study 1 that the effect seemed to “overspill” to the ‘watch’ condition, and supports the notion that tDCS does indeed have a neuromodulatory effect. However it was also shown that affect ratings were lower for participants receiving anodal stimulation when reappraising than when watching, supporting the increased efficacy of reappraisal when implemented in conjunction with anodal stimulation.

A directional hypothesis about the effect of tDCS polarity on emotion regulation had been made, namely that anodal would have a facilitatory effect whereas cathodal would have an inhibitory effect, given the known mechanisms of action, and previously reported behavioural effects, of each type of stimulation. However no evidence was found of any inhibitory effect of cathodal stimulation upon any of the self-report or peripheral measures. The exact reasons for this are unclear but there may be a number of explanations. Firstly, cathodal stimulation has yielded inconsistent results in the literature, with its effects less well defined than anodal stimulation in cognitive paradigms, and less well defined on a physiological level (Zheng *et al.,* 2011). There is also the possibility that even if cathodal stimulation had resulted in inhibition of the lDLPFC, this may not necessarily on its own have interfered with the ability of an individual to perform cognitive reappraisal as they still may have been area to recruit that area to a great enough ‘extent’ to still successfully engage in regulation. Other areas of the frontal cortex may also have been recruited to ‘compensate’ for this inhibition. It is also possible that inhibition of inhibitory neurons may ultimately actually lead to improvements in function due to the ‘double negative’ of inhibiting inhibitory processes. Some previous studies investigating the effects of cathodal stimulation have found facilitatory effects on performance, such as enhancement of planning ability (Dockery *et al.,* 2009), which would support explanations in terms of these mechanisms.

Study 2 (expressive suppression) showed no significant main effect of stimulation type on any of the self-report outcome measures, going against the initial hypotheses. One possible explanation for the lack of observable effects is that expressive suppression, as conceptualized by the nature of instructions used in this study, focuses on the outward display of the emotional experience. The strategy could therefore be considered more of a behavioural strategy than a cognitive one (see section 1.2.1 of chapter 1), meaning that the application of tDCS to an area such as the lDLPFC, known to be involved in more high-level cognitive functions, might not impact upon expressive suppression to the same extent. In this study although suppression did lead to decreased ratings of emotional experience in comparison to watching, this was at a trend level, therefore lending further support for the notion that expressive suppression is generally seen as a less effective strategy than cognitive reappraisal (Gross, 1998). Although activation of lateral prefrontal areas such as DLPFC have been reported during both reappraisal and expressive suppression (Goldin *et al.*, 2008), the role of lDLPFC in expressive suppression is certainly less well established than for cognitive reappraisal (indeed there is still a relative paucity of literature investigating the neuroanatomical basis of expressive suppression and other response focused emotion regulation strategies). Furthermore the exact role of lDLPFC in the regulation of emotion is likely to be different; whereas in reappraisal the lDLPFC is likely to play a role in aspects intrinsic to the process such as narrative construction, working memory, etc (see section 1.4, 1.4.2 in chapter 1), in expressive suppression the involvement might reflect other processes such as internal monitoring. Therefore stimulation of the area may have differential results dependent upon the nature of the cognitive tasks being carried out by an individual, and may have different results dependant on the exact contribution that those processes make to the successful control of emotion by that strategy.

### 4.11.3 Effect of tDCS on SCR

It was found that, particularly in study 1 (reappraisal), anodal stimulation was associated with lower ISCR values than for cathodal or sham stimulation. This was in accordance with the hypotheses. Given that ISCR reflects the total electrodermal activity within a particular timeframe (in this case the period when the stimulus was onscreen), an index of an individual’s bodily arousal, this finding suggests that the anodal stimulation led to less ‘arousal’. This may be due of the facilitatory effect of anodal stimulation on emotion regulation, meaning that participants were better able to regulate their emotional responses which are reflected in lower arousal and electrodermal activity (e.g. Driscoll, Tranel & Anderson, 2009).

It is unlikely that the anodal stimulation in itself directly affected the SCR data (i.e. that the change in comparison to sham stimulation was only due to the stimulation interfering with the SCR recording on a physiological level). If this was the case then a similar effect would be expected for cathodal stimulation, given that the same level of current was delivered between electrodes positioned in the same locations. However this was found not to be the case.

## 4.12 Limitations

There are limitations of the current study which should be noted. Firstly, a between subjects design was used for both studies whereby each participant only received one type of tDCS stimulation (anodal, cathodal or sham). This therefore limits the power of the design in that effects cannot be compared within participants, leaving open the possibility that differences between stimulation types might be simply due to chance. However given the significant differences that emerged in study 1 (reappraisal) in terms of both the self report and peripheral skin conductance measures, and the fact that the three stimulation type groups within each study were matched on all measures including disgust sensitivity, it seems unlikely that the results within each study are not due to any systematic differences between the groups.

One main limitation is that the heterogeneous nature of the two groups used in study 1 and study 2 also means that direct comparisons between the two groups must be treated with caution. Further work should attempt to match participants in the two different studies for underlying characteristics such as disgust sensitivity (i.e. use equal numbers of medical students).

Although experimenter bias in the two studies was minimized by only randomizing participants to a stimulation-type following the consent, neuropsychological measures and practice phases, future studies should nevertheless also employ a double-blind procedure to ensure that the investigator is blind to stimulation type and therefore removes any possibility that any aspect of the experimenter’s behaviour would indicate to participants which type of stimulation they would receive. However within the current studies even if participants had been picking up any ‘cues’ from the experimenter about which stimulation condition they were in it is unlikely to have influenced their self-report measures as participants were unlikely to know directional hypotheses had been made on the basis of polarity of stimulation, given that almost all participants had no degree of familiarity with tDCS and its proposed mechanisms.

### 4.12.2 Further studies

Future studies should also investigate the role of other frontal areas known to be involved in voluntary emotion regulation such as the rDLPFC and also more medial and ventro-lateral areas (i.e. such areas identified in Kalisch,2009, and within the data reported in chapter 2 and 3 of this thesis). This would shed further light on which components of this frontal network are most critical to the process of emotion regulation, and further investigate the specificity of tDCS stimulation. Such an investigation might also be able to reveal more about the specific processes underpinning emotion regulation.

## 4.13 Clinical applications

The finding that anodal tDCS had a facilitatory effect on an individual’s ability to regulate their emotions by reappraisal fits in with an increasing literature on the potential neuro-enhancement by anodal stimulation of cognitive functions (e.g. Cohen Kadosh *et al.*, 2010, Dockery *et al.,* 2009). Evidence obtained from the current research, in addition to previous studies on the effect of tDCS on emotional experience (Pena-Gomez *et al.,* 2011*,* Boggio *et al.,* 2009), also suggests that tDCS stimulation may be able to eventually be used clinically. For example, it may be able to be used to help patients with major depression become more effective at regulating negative emotion. Repeated administration with tDCS may be able to ensure that such changes are longer lasting than just a single session (Nitsche *et al.,* 2009).

## 4.14 Conclusion

The two studies in this chapter aimed to ascertain whether tDCS could be used to modulate emotion regulation ability by facilitating, or inhibiting, neuronal activity in the left DLPFC. Study 1 demonstrated that anodal stimulation is effective in reducing subjective affect ratings when implementing cognitive reappraisal to regulate emotion to disgusting video stimuli. Furthermore, anodal tDCS had a significant effect on SCR, with reduced SCR in comparison with a sham condition. This study therefore contributes to a growing body of evidence for the effectiveness of tDCS as an experimental technique, as well as successfully designing a paradigm which could be utilised in further studies to increase the understanding of the process of emotion regulation, and the efficacy of tDCS, both in healthy volunteer samples, and patient groups.

# Chapter 5 – Structural correlates of emotion regulation

The initial background literature review in chapter 1 focused on the literature investigating the functional basis of emotion regulation. This was used to identify a number of unexplored research questions surrounding the functional neural basis of emotion regulation, which resulted in three studies that have been described in chapters 2, 3 and 4.

Given that the studies described in chapters 2 and 3 collected high-resolution structural scans in addition to the functional scans (for purposes of normalization during pre-processing), it was also possible to use these scans and conduct additional analyses to investigate possible structural relationships with measures of emotion regulation.

## 5.1 Voxel-based morphometry (VBM)

The method used in order to investigate structural variation with measures of interest was voxel based morphometry (VBM; Ashburner & Friston, 2000). Briefly, this approach involves normalization of a high-resolution structural brain scan to a template, and segmenting each into grey matter, white matter, and cerebro-spinal fluid (CSF). VBM allows for an investigation of which areas of the brain demonstrate volumetric differences in relation to a variable (or variables) of interest. Voxel-based morphometry has shown to be a particularly effective method at distinguishing features of a clinical group in comparison to a control group, for example in neurodegenerative disease such as Alzheimer’s (Ferreira *et al.,* 2011), as well as being able to investigate the structural basis of neuropsychiatric symptoms in such conditions (Bruen *et al.*, 2008). VBM also allows for the use of regression analyses to investigate structural factors in relation to continuous variables of interest, such as the score on a particular psychometric measure.

Due to the automated methods, voxel based morphometry can be regarded as a relatively ‘unbiased’ method in comparison to more manual tracing techniques (Whitwell, 2009). VBM also seems to be comparable to such manual tracing methods in terms of accuracy and sensitivity (Whitwell, 2009).

## 5.2 VBM studies of emotion regulation

A number of investigations have shown that the use of habitual voluntary emotion regulation strategies, such as expressive suppression and cognitive reappraisal (Gross, 1998), are associated with accompanying changes in grey matter volume in brain areas such as the insula (Giuliani *et al.,* 2011; expressive suppression) dorso-medial prefrontal cortex (Kuhn, Galinat & Brass, 2011; expressive suppression) and dACC (Giuliani, Drabant & Gross, 2011; cognitive reappraisal). Another study also found that grey matter volume within the right pars opercularis region of the IFG is correlated with performance on a reappraisal paradigm (Tabibnia *et al.,* 2011). However to date there have been no investigations of whether an individual’s implicit tendency to engage in automatic emotion regulation might also be reflected in underlying grey matter volume differences. Although studies that have investigated the grey matter volume differences associated with self-report use of habitual emotion regulation strategies are informative of the neural basis of emotion regulation, such investigations have an inherent limitation due to the fact they rely on self-report from participants and may be subject to social desirability biases or demand characteristics.

Given the prevalence of automatic emotion regulation in everyday life (Mauss, 2007), and the data obtained in chapter 3 of this thesis demonstrating that automatic forms of emotion regulation may have a dissociable neural basis from voluntary emotion regulation, it is likely that an individual’s tendency for automatic emotion regulation might also be reflected in the underlying grey matter volumes of the brain areas that support such automatic processes. However reliably measuring an individual’s tendency to engage in automatic emotion regulation is problematic, given that automatic emotion regulation is said to occur in a manner whereby it is not noticeable or under conscious control of the individual (Mauss, 2007).

## 5.3 ER-IAT

In order to capture the underlying tendency of an individual to engage in automatic emotion regulation, Mauss (2006) developed an adaptation of the existing Implicit Association Test (IAT; Greenwald, McGhee & Schwartz, 1998), known as the Emotion Regulation Implicit Association Test (ER-IAT). The classic IAT provides a measure of an individual’s underlying automatic associations of different concepts, in order to reveal an underlying implicit bias, or preference, for a particular category. The IAT requires participants to pair together words relating to different concepts, and works on the basis that individuals are faster at pairing together categories when the pairing is congruent with their implicit attitude. Such an approach has been used to indicate underlying implicit biases such as racial stereotyping (Greenwald, McGhee & Schwartz, 1998), self esteem (Greenwald & Farnham, 2000) and gender stereotyping (Nosek, Banaji & Greenwald, 2002).

The emotion regulation adaptation of the test (ER-IAT) maintains that individuals who have an underlying ‘preference’ for emotion regulation (i.e. a habitual/automatic emotion regulation style) are faster at pairing words pertaining to emotion regulation (e.g. control, contain) with positively valenced words (e.g. gold, honor) than with negatively valenced words (e.g. gloom, bad). Equally, negatively valenced words are quicker to be classified with emotion ‘expression’ words (e.g. express, reveal).

One study (Mauss *et al*., 2006) revealed that the ER-IAT was associated with the ability to regulate the emotion of anger, in terms of physiological measures such as cardiac output and sympathetic activation. Specifically, those participants who had a ‘positive’ implicit attitude towards emotion control demonstrated reduced subjective feelings of anger, and greater sympathetic activation, cardiac output, and a lower total peripheral resistance (all of which indicated and ‘adaptive’ physiological profile).

## 5.4 Hypotheses

Given that the ER-IAT seems to offer a measure of an individual’s tendency to engage in automatic emotion regulation it was therefore investigated using VBM whether an individual’s tendency to engage in automatic emotion regulation might be reflected in differences in the underlying neuroanatomical correlates.

It was hypothesized that an individual’s tendency to engage in emotion regulation, as indexed by their score on the ER-IAT would be associated with differences in grey matter volume within regions known to be functionally involved in emotion regulation, specifically DLPFC, VLPFC, and ACC (Oschner & Gross, 2005, Goldin *et al.*, 2008, Banks *et al*., 2007, Van Reekum *et al*., 2007) and also within regions that had previously been shown to demonstrate structural differences in relation to habitual emotion regulation style, specifically insula (Giuliani *et al*., 2011), dorso-medial prefrontal cortex (Kuhn, Galinat & Brass, 2011) and dACC (Giuliani, Drabant & Gross, 2011). This was based on the reasoning that a greater tendency to engage in automatic emotion regulation might be reflective of a relative ‘ease’ of recruitment of emotion regulation processes, working on the notion that automatic behaviours are generally associated with efficiency in neural processing (Kubler, Dixon & Garavan, 2006). This is then likely to be reflected in the underlying grey matter volume within the relevant areas; for example within the context of emotion regulation this might include frontal areas such as DLPFC and VLPFC. However given that the fMRI data obtained in chapter 3 identified a role for right VPC and rIFG in emotion regulation by implementation intentions (a form of more automatic emotion regulation), it was also hypothesized that these areas may show differences in relation to the ER-IAT score. The direction of this change might involve increased grey matter regions if this network is engaged more frequently by individuals with a greater tendency to engage in automatic emotion regulation, however the regions may also demonstrate reduced volumes if the increased tendency to engage in automatic emotion regulation is supported by efficiency of processing with such regions.

## 5.5 Materials and Methods

### 5.5.1 Participants

This investigation used data from 34 participants (18 male) who had taken part in the study described in chapter 3 of this thesis, mean age 20 (range 18–22). All were recruited from the local student population. Exclusion criteria included any current psychiatric or neurological disorder or contraindication to MR imaging. Written informed consent was obtained from all participants. All participants were right-handed as assessed by the Edinburgh Handedness Inventory (mean score = 70, Oldfield, 1971).

The ER-IAT was conducted with these participants as part of an additional study, which does not form part of this PhD thesis.

### 5.5.2 Behavioural measures

### 5.5.3.1 ER-IAT

Participants completed a computerized version of the ER-IAT, run using E-Prime (version 2). Participants had to classify words related to four categories (emotion expression, emotion regulation, positive, negative). The ER-IAT consists of five blocks. The two critical blocks require participants to classify categorized items into two combined categories: emotion regulation and positive items versus emotion expression and negative items. The second critical block required participants to categorize items in the opposite fashion: emotion expression and positive items versus emotion regulation. The three remaining blocks comprise practice trials that aim to provide a measure of each participants ‘general’ processing speed and reaction time. Details of the scoring are given in section 5.7.1.

### 5.5.3.2 Personality Inventory

Participants also completed the revised short-scale version of the Eysenck Personality Questionnaire (Eysenck, Eysenck & Barrett, 1985) which gives a score for the five dimensions of personality; neuroticism, extraversion, openness to experience, conscientiousness, and psychoticism. There was a particular question of interest as to whether the dimensions of neuroticism and extraversion would correlate with the participant’s scores on the ER-IAT. Any of the subscales that showed a correlation with performance on the ER-IAT could be added as a covariate for the VBM analysis. This is based on the finding that the neural basis of emotion processing (Hamann & Canli, 2004) and voluntary emotion regulation (Harenski, Kim & Hamann, 2009) has been shown to have an association with personality and furthermore that the effects of brain stimulation designed to modulate emotion regulation have been shown to be mediated by neuroticism and extraversion (Pena-Gomez *et al.*, 2011).

## 5.6 MRI data acquisition

Participants were scanned on a Philips 3T scanner (Achieva, Philips Medical Systems, Best, NL). A high resolution T1-weighted structural scan was also collected from each participant (3D gradient echo, MP-RAGE, TR = 10.5 ms; TE = 4.8 ms; spatial resolution = 0.8mm3). Head movement was minimised using foam padding. Functional scans were obtained prior to this and have been reported in chapter 3.

## 5.7 Data Analysis

### 5.7.1 ER-IAT

Average latencies of practice and test trials were divided by the resulting standard deviations. The ER-IAT score for each participant was calculated by subtracting averages from the average response time in the two critical blocks. This scoring method gives a ‘D’ value which indicates the participants underlying tendency to engage in automatic emotion regulation. The higher this value the greater the tendency to engage in automatic emotion regulation. This scoring procedure was exactly the same as described by Greenwald, Nosek, & Banaji (2003).

### 5.7.2 VBM

Scan data were analyzed with SPM8 (http:www.fil.ion.ucl.ac.uk/spm). Images were segmented into gray matter (GM), white matter (WM) and cerebrospinal fluid (CSF) by a unified tissue-segmentation procedure following image intensity nonuniformity correction. The GM, WM and CSF volumes were summed in order to give total brain volume (TBV).

Native-space GM images were registered to a study specific template that was generated using a high-dimensional non-linear diffeomorphic registration algorithm (DARTEL; Ashburner, 2007) which has been shown to minimise structural variation between participants. The spatially normalized images were then smoothed with an 8mm FWHM Gaussian kernel.

The resulting images were analyzed using multiple regression within SPM8. In order to prevent edge effects voxels with an intensity value below 0.2 were excluded from the analysis. Each participant’s ER-IAT score was entered as the dependent variable of interest, with age, gender, and TBV entered as covariates of no interest. Results are presented at p<.05 corrected for multiple comparisons using family-wise error (FWE) correction.

## 5.8 Results

### 5.8.1 Personality inventory

There were no significant correlations between the ER-IAT scores and any of the five subscales of the personality inventory (Pearson correlations, all p>.05).

### 5.8.2 ER-IAT

The mean score on the ER-IAT was -0.14 (range -0.99 to 0.84, SD=0.44).

### 5.8.3 VBM

An area of left dACC (MNI -8 9 30, BA24, extent threshold=122) was associated with inter-individual variability in ER-IAT score (Figure 5.1). Specifically, those individuals who had a lower tendency to engage in emotion regulation (i.e. those who ‘prefer’ expression of emotion) exhibited greater grey matter volume within this region. Results were thresholded at p<.05, whole-brain FWE corrected. As seen in Figure 5.1, the left ACC was the only area that was associated with regional grey matter volume differences in relation to the ER-IAT score. When threshold was set at p<.001 uncorrected the only other significant area was a region of right DLPFC (MNI 40 2 36; BA9).



Figure 5.1 – Brain areas demonstrating differences in grey matter thickness as a function of score on the ER-IAT. An area of left dACC was the only region found to be significantly associated (p<.05, whole-brain FWE corrected).

## 5.9 Discussion

The study described in this chapter aimed to investigate whether or not an individual’s tendency to engage in automatic emotion regulation would be associated with regional grey matter volumes in the brain. It had been hypothesized that this tendency might be reflected in grey matter volume differences in regions known to be involved in the regulation of emotion, specifically DLPFC, VLPFC and ACC, which may also demonstrate an effect on other regions such as insula volume.

Partial support for this hypothesis was obtained by the finding that an area of left dACC (BA24) was indeed associated with differences in tendency to engage in automatic emotion regulation. Specifically, those individuals who had reduced tendency to engage in automatic emotion regulation exhibited greater grey matter volume. The dACC has previously been implicated in the voluntary cognitive control of emotion (e.g. Ochsner *et al*., 2002, Kalisch, 2009, Giuliani, Drabant & Gross, 2011), therefore was one region that was hypothesized might vary in grey matter volume in relation to the individual’s tendency to engage in automatic emotion regulation.

No evidence was found that tendency to engage in emotion regulation was associated with any differences in grey matter within any other areas of the brain, including those in frontal cortex such as DLPFC, VLPFC, vmPFC known to be involved in voluntary emotion regulation. One reason for the lack of any differences may be that these areas have previously been identified in being involved in voluntary emotion regulation (Kalisch, 2009, Ochsner & Gross, 2005, Kuhn, Galinat & Brass, 2011). Such processes involve emotion regulation that is performed under conscious control and in an effortful and deliberate fashion. However the measure used in this investigation, the ER-IAT, provides a measure of an individual’s tendency to engage in *automatic* emotion regulation; this may therefore account for why this was not reflected in changes in grey matter volume of areas implication in voluntary emotion regulation, such as DLPFC and VLPFC, VMPFC or insula. There was also no evidence found that the areas identified in chapter 4 as being involved in implementation intention-enabled emotion regulation, the right IFG and rVPC, showed any variation in grey matter volume in relation to tendency for automatic emotion regulation.

One interpretation for the specific role that the dACC plays in the tendency to engage in automatic emotion regulation might relate to its proposed role as the ‘neural alarm’ system of the brain. Eisenberger & Lieberman (2004) proposed that the dACC is involved is signalling the need for behavioural or cognitive control. Such a function would clearly be in line with models of emotion regulation, whereby the need for cognitive control to regulate the emotion might be signaled by activation of the dACC. Giuliani, Drabant & Gross (2011) previously found that the grey matter volume of a similar area of dACC was positively correlated with an individual’s self reported typical use of cognitive reappraisal. When compared with Giuliani, Drabant & Gross (2011) it might seem counterintuitive that individuals with a more positive attitude towards emotion regulation would display reductions in grey matter volume of dACC, rather than an increase, given that cognitive reappraisal is generally seen as a highly adaptive emotion regulation strategy (Gross & John, 2003). However one explanation might be that individuals more likely to engage in automatic emotion regulation, might require less of an ‘alarm’ signal from the dACC to engage in voluntary emotion regulation, because of their tendency to engage in regulation on a more automatic basis. An alternative explanation might be that individuals with a smaller dACC volume adopt a more automatic style of emotion regulation given that they may be less efficient at engaging in ‘voluntary’ emotion regulation such as cognitive reappraisal, as is suggested by Giuliani, Drabant & Gross (2011).

There is also an interesting related line of investigation about the role of the dACC in the regulation of autonomic factors such as heart rate. Critchley *et al*., (2003), suggest that the role of the dACC is to mediate context-driven modulation of bodily arousal. They found that activation of the dACC was related to control of heart rate during a paradigm involving cognitive and motor control, with the interpretation that dACC coordinates cardiovascular arousal during effortful motor or cognitive control. This is particularly interesting given that the ability to regulate emotion is also linked to an individual’s underlying cardiac tone (Pu, Schmeichel & Demaree, 2009). Pu and colleagues found that individuals with a higher respiratory sinus arrhythmia (RSA) (i.e. increased cardiac control) were judged to have expressed less emotion than those with a low RSA, even though the self reported emotion experience was similar. The authors suggest that cardiac vagal control may act as an internal marker of self-regulatory tendencies. Taken together this previous research and the current findings suggest that the dACC volume may act as an internal marker for emotion regulation tendency, as a result of its involvement in the regulation of bodily arousal.

## 5.10 Limitations

One limitation of the VBM investigation described in this chapter is that, as is the case with any cross-sectional investigation of this nature (e.g. Giuliani *et al.,* 2011), no inferences can be drawn about the causality of any relationship between brain volumes and the psychological phenomena of interest. It is not possible to definitively say whether an individual’s attitude towards emotion regulation is influenced by the nature of the grey matter volume with ACC, or whether volumetric changes are a result of this attitude being held over time.

Another shared limitation with previously published work (Giuliani *et al*., 2011, Kuhn, Galinat & Brass, 2011) is that the study investigates the relationships in a population of younger adults (age range 18-22). It is therefore unclear whether a similar relationship would be observed in an older population. This is particularly important given the fact that brain plasticity and grey matter volume changes do not occur at the same rate across the lifespan (Giorgio *et al.*, 2010, Ziegler *et al*., 2012), and aspects of emotional experience and regulation have been shown to change into later adulthood (Van Reekum *et al*., 2011). Further investigations are therefore needed to ascertain whether the association between ACC volume and tendency to engage in automatic emotion regulation is maintained in later adulthood. Further studies are also needed regarding the stability of the ER-IAT measure over time to further investigate whether an individual’s tendency to engage in automatic emotion regulation is relatively ‘fixed’ or subject to change over time as a result of experience.

## 5.11 Conclusion

The findings of this study indicate that an individual’s tendency to engage in automatic emotion regulation, as indexed by their performance on the ER-IAT, is related to volumetric differences within the left dACC, which may influence emotion regulation by its modulatory effects on physiological arousal, and by signaling the need for conscious cognitive control. The study adds further weight to the notion that the way in which individuals regulate emotion is influenced by the underlying grey matter volumes within regions such as the dACC.

# Chapter 6 - General Discussion

The studies described in this thesis have utilized behavioral, fMRI, tDCS, and VBM methodology to address various questions concerning the neurophysiological basis of emotion regulation. Three primary research questions of interest were addressed that were identified from a review of the previous emotion regulation literature.

* The first of these questions aimed to identify the neural basis of emotion regulation where the target of the regulation is another person (interpersonal emotion regulation) rather than the self (intrapersonal emotion regulation).
* The second research question of interest was whether strategies for intrapersonal emotion regulation that differ in their effortful nature might show a differing neurophysiological basis. Specifically this investigated how emotion regulation supported by ‘implementation intentions’, that achieve their effects in a relatively ‘automatic’ fashion, show a differing neural basis to effortful strategies.
* The final question concerned whether intrapersonal emotion regulation might be modulated by the brain stimulation technique of transcranial direct current stimulation (tDCS) based on the existing understanding of the neural basis of voluntary intrapersonal emotion regulation.
* An additional analysis was also conducted following completion of these studies that used the high-resolution structural MRI scans obtained during the study reported in chapter 3 to investigate the relationship between automatic emotion regulation and structural differences in grey matter volumes within the brain.

This chapter will summarize the findings from each of these investigations, discuss the broader themes to emerge from them, and discuss how they interrelate. The limitations of the current thesis will also be discussed and avenues for further investigations proposed.

## 6.1 How has the thesis advanced understanding of the neural basis of emotion regulation?

The series of studies described in this thesis have investigated different aspects concerning the neurophysiological basis of emotion regulation in humans. These studies have attempted to address several gaps in the literature and provide a furthering of the knowledge base. Specifically, the studies have investigated the neurophysiological basis of processes related to emotion regulation that have been studied on a phenomenological level but which had not yet been studied in terms of their underlying neuronal mechanisms. For example, a taxonomy of strategies for interpersonal emotion regulation has previously been identified (Niven, Totterdell & Holman, 2009) but prior to this thesis there had been no investigation into what the neural underpinnings of interpersonal emotion regulation processes might be. The need to address such gaps in the knowledge base is potentially important given that deficits in intrapersonal and interpersonal emotion regulation have also been shown to contribute to difficulties observed in psychiatric illness. For example, deficits in interpersonal functioning in psychiatric conditions such as schizophrenia have been identified as a typifying symptom (e.g. Frith, 1983, Collip *et al.*, 2011). Deficits in the ability to regulate other people’s emotions by way of interpersonal emotion regulation are therefore also affected in such conditions.

### 6.1.1 The neural basis of interpersonal emotion regulation

The fMRI study of interpersonal emotion regulation detailed in Chapter 2 has provided the first such investigation into what neural processes support the process of regulating another person’s emotion. Although the neural correlates of more general social interaction are beginning to become understood (Jackson & Decety, 2004, Redcay *et al.*, 2004), the question of how specific neural systems support interpersonal emotion regulation had yet to be addressed. The approach taken was a novel fMRI paradigm in which participants were required to interact with another person during an fMRI scan in an attempt to regulate that person’s emotional responses to stimuli being presented concurrently on the screen. This was furthermore compared with an equivalent condition in which the participants were required to only regulate their own emotional responses. This study found that though both regulatory processes shared an overlapping network of activations including left lateral frontal cortex and pre-supplementary motor area, interpersonal emotion regulation was also supported by activations within areas of the brain known to be involved in the ‘social’ brain and aspects of social cognition. Specifically this included involvement of areas known to be involved in ‘mentalizing’ or ‘theory of mind’; essentially the ability to attribute emotional states to another person. This included areas of the brain such as the left anterior temporal pole (BA 38) and medial prefrontal cortex.

The results of chapter 2 suggest that the processes of interpersonal emotion regulation are dissociable on a neural level from those supporting intrapersonal emotion regulation. This was found to be the case even though the nature of the task involved many of the components being replicated across both conditions, such as the presence of the emotion-eliciting stimuli, the presence of the other person, and the spoken components of the task. The fact that differences were found between the two different types of regulation is therefore noteworthy, especially given that both regulation types (intra- and interpersonal) are already a comparatively ‘high level’ contrast in that they had been contrasted against an equivalent no-regulation condition (the ‘watch’ condition).

### 6.1.2 The neural basis of automatic emotion regulation

The thesis also extended the existing literature on the neural basis of intrapersonal emotion regulation by investigating the way in which the neural basis of emotion regulation might differ according to its more automatic, or less automatic, nature. The need for such an investigation was driven by the comparative paucity of investigations that have investigated the control of emotion by more ‘automatic’ or less effortful processes, in comparison to a fairly well established literature on voluntary and effortful emotion regulation. Although a number of studies have investigated automatic emotion regulation as conceptualized as regulating emotions elicited by, for example, emotional faces being presented as a background during a task (e.g. Phillips, Ladoucer & Drevets, 2008), few studies have investigated automatic emotion regulation to stimuli that are similar to those used in investigations of effortful emotion regulation, such as IAPS or video stimuli.

The approach taken to addressing this question was to attempt to strategically automate emotion regulation processes by way of implementation intentions, which were introduced in chapter 3 as ‘if-then’ plans which support emotion regulation by providing a link between the requirement for regulation and a goal-directed regulatory action. Implementation intentions are able to facilitate effective emotion regulation, and achieve their results in a manner that might be considered more ‘automatic’ than previously studied strategies (Gallo-Schweiger *et al.,* 2012).

The paradigm used in chapter 3 was based on previous investigations of the neural basis of voluntary emotion regulation (e.g. Oschner *et al.,* 2002) and involved the presentation of a series of IAPS images, to which participants were required to either regulate their emotional responses or attend to the image without trying to control their response. A word appearing onscreen prior to the presentation of each image (either reappraise/suppress or attend) cued the participant as to which instruction should be followed for each image. The crucial manipulation of the experiment was the nature of the instructions that participants received. Half of the participants received emotion regulation instructions very similar to those widely used previously in investigations of ‘voluntary’ emotion regulation, comprising what might be deemed ‘goal intention’ strategies (e.g. Gross, 1998). The other half of participants received the same instructions but had them furnished with an ‘implementation intention’ that specified exactly what they should do when they encountered the appropriate cue (e.g. “If I see reappraise, then I think these are just pixels on a screen and the image can’t get to me!”).

The results showed that the self-reported efficacy of emotion regulation was enhanced for those who had received the implementation intention instruction than those who received the goal intentions instruction. Furthermore there were dissociable differences at a neural level. Goal intentions recruited frontal areas previously observed in similar paradigms, including lateral frontal cortices. Implementation intentions, however, resulted in a marked pattern of activation within the right IFG and right VPC. Both of these areas have been implicated in mechanisms of attentional control, and support the idea that implementation intentions promote the attentional capture of relevant cues for action. When directly comparing between the strategies it was also revealed that the goal intentions instruction was associated with higher levels of activity within the left amygdala in comparison to the implementation intentions group, providing further evidence that the increased efficacy of emotion regulation of implementation intentions is reflected on a neural level, given the finding of a correlation between reduction in amygdala activation by emotion regulation and decrease in self-reported affect ratings. Furthermore connectivity analyses of the left amygdala revealed that whilst for goal intentions the modulation of amygdala appeared to be driven by areas of frontal cortex such as DLPFC, in accordance with existing literature (Banks *et al*., 2007), implementation intentions did not show this pattern, suggesting that the effects of emotion regulation supported by implementation intentions are exerted in a distinct fashion from goal intentions.

### 6.1.3 The modulation of emotion regulation by brain stimulation

The third primary research question of the thesis investigated whether intrapersonal emotion regulation ability can be improved (or inhibited) by external stimulation of brain areas known to be involved in emotion regulation. This used tDCS stimulation to target the lDLPFC during a voluntary emotion regulation paradigm. It was found that there was a facilitatory effect of anodal tDCS stimulation on emotion regulation by cognitive reappraisal, in terms of both self report affect ratings and skin conductance response (an index of physiological arousal). However no such effect was found for an expressive suppression instruction. No effect was also found for cathodal stimulation of the same area for either type of regulation. This investigation provides further evidence for the importance of the lDLPFC in voluntary emotion regulation by showing that facilitatory stimulation has a self-reported and physiological effect.

### 6.1.4 Structural correlates of automatic emotion regulation

The final investigation in this thesis utilized the high-resolution structural MRI scans obtained from the participants who took part in the study described in chapter 3. This investigated the relationship between brain structure and the underlying tendency of an individual to engage in automatic emotion regulation. This took the form of a voxel-based morphometry study, using a measure of tendency to engage in automatic emotion regulation as indexed by scores on the emotion regulation implicit association test (ER-IAT).

Although a number of investigations have identified grey matter volume differences in relation to habitual use of voluntary emotion regulation strategies the question of whether an individual’s tendency to engage in more automatic forms of emotion regulation is also reflected in underlying grey matter volumes had yet to be explored. A negative correlation was found between the volume of an area of left dACC and tendency to engage in automatic emotion regulation; specifically those individuals with a greater tendency to engage in automatic emotion regulation displayed reduced grey matter volume. This supports a possible role of ACC in emotion regulation in detecting the need for cognitive control, given that individuals with a lower tendency to engage in automatic emotion regulation might require more of an ‘alarm’ from the anterior cingulate to initiate regulation.

### 6.1.5 Structural and Functional correlates of automatic emotion regulation

There is clear overlap between the research question motivating chapter 3, which investigated the functional basis of automatic emotion regulation, and chapter 5, which investigated the structural underpinnings of automatic emotion regulation. The results of the two studies do not appear to overlap in that different brain areas emerged in the results. Specifically, chapter 3 identified a right lateralized fronto-parietal network that underpinned implementation intention-enabled emotion regulation, whereas the VBM investigation in chapter 5 revealed that only an area of left dACC was associated with the tendency to engage in automatic emotion regulation.

One reason for this apparent inconsistency might be that although both investigations have investigated more automatic forms of emotion regulation, they have conceptualized this in slightly different ways. Chapter 3 investigated automatic emotion regulation in one particular form, that of implementation intentions. The data reported in chapter 3 suggested that for implementation intentions, the automaticity of emotion regulation was achieved by the increased salience of the opportunity for regulatory action. In chapter 5, the form of automatic emotion regulation was defined as an implicit positive attitude towards emotion regulation, as indexed by showing different reaction times when pairing together positively or negatively valenced words with concepts of emotion expression or emotion regulation. These two constructs therefore differ in the exact manner in which they define automatic emotion regulation.

Another reason related to this is that in chapter 3 although the implementation intentions strategies promoted automatic emotion regulation, they nevertheless had to be ‘learned’ by participants at the beginning of the investigation. It is clear, therefore, that this might promote a different type of automaticity in comparison to strategies that achieve automaticity as a result of a lifetime of repeated usage. This may help explain why the implementation intentions resulted in activations within attentional control networks in the brain, given the still comparative novelty of the strategies (and cue).

Another reason for this inconsistency may be the methods themselves; it is important to remember that functional MRI is measuring metabolic changes within the brain as a proxy of functional brain activation, whereas VBM is looking only at the structure of the brain. Future studies might be able to shed further light on the neural basis of the ER-IAT by having participants perform it whilst undergoing fMRI. Such an investigation would be able to provide confirmatory evidence for the *functional* significance of the dACC in automatic emotion regulation.

It would also be interesting to investigate whether the long-term usage of implementation intention strategies would also result in volumetric changes. This might involve teaching a particular implementation intention strategy (or perhaps a suite of strategies) to participants and then following them over time to see if any behavioural changes were associated with changes in grey matter volumes within the brain. Recent evidence investigating stress-reduction programmes using ‘mindfulness’ training indicates that changes in grey matter within such regions as ACC are manifest even after periods as short as 8 weeks (Holzel *et al.,* 2011), suggesting that such an investigation into the structural changes associated with longer-term usage of implementation intentions would shed further light on the neural processes supporting them, and help to further disentangle the question of how automatic emotion regulation is supported.

## 6.2 Methodological contributions of thesis

The studies described within the thesis have generally made use of existing methodologies and methods of analysis. However there have also been certain contributions made by the thesis in terms of some of the more novel aspects of some of the approaches taken.

For example one of the more novel methodological contributions of the thesis is from Chapter 2. This chapter described development of a paradigm designed to probe the neural underpinnings of interpersonal emotion regulation, and achieved this by using a paradigm that attempted to introduce an apparent element of interactivity to attempt to address the underlying research question. Specifically this involved the participant in the scanner interacting with another person outside of the scanner. The demonstration that such interactive paradigms are feasible approaches to employ is therefore encouraging and is of great potential benefit to the field.

Although the nature of the interaction within the study was not *truly* interactive, in the respect that the video-link was in fact pre-recorded and not live, the fact that the vast majority of participants reported no suspicions that the link was not live represents a potential strength of such approaches. Specifically, such approaches might allow for the desired level of interactivity to be achieved but in a manner that retains a satisfactory level of control over parameters that need to be tightly controlled from one participant to the next within an fMRI experiment. This might include, for example, intensity of facial expression, timing of facial expression, and number of eye fixations the other person makes directly to the camera. The tight control of such variables is of critical importance to fMRI experiments and the approach taken in chapter 2 is therefore an attractive one for questions concerning the neural basis of interpersonal functioning. Interpersonal factors have been argued to be critical to furthering our understanding of emotion (Fischer & Van Kleef, 2010) and therefore any line of research that further incorporates social factors into such investigations is potentially highly valuable particularly within the field of affective neuroscience.

Another development to emerge from the tDCS component of the research (chapter 4) is further confirmation of the potential of tDCS to manipulate even comparatively complex cognitive tasks, such as voluntary emotion regulation. The only previous study into what was conceptualized specifically as emotion regulation (Pena-Gomez *et al.,* 2011) did so on an ‘implicit’ level whereby enhancing activity in lDLPFC by anodal stimulation reduced affect ratings in a passive viewing task, which was said to be a result of having enhanced emotion regulation due to stimulation. The results of chapter 4, however, suggest that emotion regulation can even be enhanced when it is conducted in a cognitively complex, ‘voluntary’ fashion.

## 6.3 Future directions

The series of studies described in this thesis have covered broad scope of research questions surround the neurophysiology of emotion regulation. As such there are a number of different directions that could be pursued further to investigate the questions that motivated each original research question, and new ones that have emerged from the investigations.

One such direction that emerges from chapter 4 would be to investigate whether tDCS, having been shown (for anodal stimulation) to have a facilitatory effect on voluntary emotion regulation, could also potentially have an effect on more automatic forms of emotion regulation, such as implementation intentions. This research question is also based on the findings of Pena-Gomez *et al.,* (2011), who found that stimulation of lDLPFC seemed to induce more ‘automatic’ emotion regulation processes, even in the absence of an instruction to do so.

The rationale for such an investigation into whether tDCS could impact upon emotion regulation is provided by the finding of a clearly defined network that was involved in the process of emotion regulation by implementation intentions in Chapter 3, namely the rVLPFC and rVPC. A tDCS investigation could potentially further investigate the importance of the contributions made by these particular areas to the effectiveness of the emotion regulation process. For example, it may be possible to assess the relative contribution of each area by stimulating the region prior to the task in order to assess whether facilitation of either area would further enhance efficacy of emotion regulation by implementation intentions. For example, it might be hypothesized that the efficacy of implementation intentions might be even further enhanced by stimulation of the right VLPFC, which was activated by the requirement for regulation by implementation intentions, and may reflect the attentional capture of the cue word appearing. If this attentional control mechanism was enhanced it may be possible that the relative automaticity of implementation intentions may be even further enhanced.

It remains a possibility, however, that such an approach may not necessarily lead to an improvement in emotion regulation ability. The attentional control network observed (e.g. Hampshire *et al.,* 2007) appeared to function successfully in the implementation intentions group in chapter 3 and appears to be contributing significantly towards the associated efficacy of emotion regulation. It may be that although facilitation of any of these areas even by up-regulating the activity of one of the identified areas may be expected to lead to an improvement in emotion regulation ability, along the lines of the approach taken in chapter 3, the more ‘automatic’ nature of this attentional control network means that any modulation of the network may lead to a disruption of the network due to imbalance. Essentially, the attentional control network may exist in a ‘balanced’ state that may be not amenable to manipulation. Further studies are needed to further investigate these possibilities.

## 6.4 Emotion regulation and psychiatric illness

All of the investigations described in this thesis have clear potential implications for our understanding of how emotion dysregulation may manifest in psychiatric illness, and how such dysregulation might be treated.

### 6.4.1 Previous work on the neural basis of emotion regulation in psychiatric illness

Dysfunctional regulation of one’s own emotion has been implicated in a wide range of psychiatric conditions; in fact the vast majority of psychiatric disorders as defined by the Diagnostic and Statistical Manual of Mental Disorders (DSM) feature an aspect of emotion dysregulation as one of the defining symptoms. A number of studies have revealed differences, compared with control participants, in the neural circuitry of voluntary regulation of emotion (as opposed to differences in the *experience* of emotion itself). Such studies have identified disturbances, particularly in the involvement of frontal cortex, in the regulation of affect. These studies have included investigations of individuals with bipolar disorder (Almeida *et al.,* 2009; Foland *et al.,* 2008; Phillips *et al.,* 2008); major depression (Beauregard, Paquette & Levesque 2006; Johnstone *et al.,* 2007; Fales *et al.,* 2008); specific phobia (Herman *et al.,* 2009); impulsive aggression and violence (Davidson *et al.,* 2000); generalized anxiety disorder (Etkin *et al.,* 2010); social anxiety disorder (Goldin *et al.,* 2009); individuals with high trait anxiety (Campbell-Sills *et al.,* 2010); post-traumatic stress disorder (New *et al.,* 2010), and post-partum depression (Moses-Kolko *et al.,* 2010). It has also been suggested that blunted affect, typically observed in individuals with schizophrenia, might be due to over reliance on regulation strategies of expressive suppression rather than reappraisal (van der Meer *et al.,* 2009).

In addition, it has been suggested that the cognitive regulation of craving, as related to drug addiction, may in itself be seen as a form of emotion regulation (Kober *et al.,* 2010), and that this process relies on subcortical modulation by prefrontal areas (which is similar to the process of emotion regulation as described in chapter 1). It has even been recently suggested that repetitive nightmares (known to be heightened in some psychiatric disorders, Ohayon, Morselli & Guilleminault, 1997) might be underpinned by deficits in emotion regulation (Levin & Nielsen, 2009).

The prevalence of emotion dysregulation in psychiatric illness has led to such dysregulation becoming a specific target for treatment. In cognitive therapies there has been a move towards specifically targeting emotion regulation skills in addition to conventional cognitive-behavioural therapy (CBT)-based approaches; early trials indicate improved patient outcomes (Berking *et al.,* 2008). There has been a particular emphasis on emotion-focused cognitive-behavioural therapy aimed at addressing emotion dysregulation underlying internalizing disorders in youth (see Trosper *et al.,* 2009). Recent evidence also suggests that cognitive training in the treatment of schizophrenia leads to functional changes in activity within areas of frontal cortex associated with executive tasks (Haut, Lim and MacDonald, 2010). As emotion regulation could be said to incorporate a number of executive processes, this may potentially lead to improvements in emotion regulation following cognitive training, though this question has not been specifically addressed to date.

Emotion regulation abilities are also targeted as part of more ‘holistic’ therapeutic approaches such as ‘mindfulness training’ and mediation, which place focus on introspection and self-regulation of attention. Recent findings investigating ‘mindfulness training’ and meditation have also revealed structural grey matter changes associated with continued use of the techniques in areas implicated in emotion regulation, such as orbitofrontal cortex. For example, a study of long-term meditators found that increased meditation was associated with increases in grey matter volumes within orbitofrontal cortex and left inferior frontal gyrus (Luders *et al.,* 2009), both of which are involved particularly in the response-inhibition component of emotion regulation. Such structural changes might therefore provide a basis to account for behavioural findings of improved emotion regulation following long-term meditation practice. Such findings have led to particular interest in whether such approaches might be useful in the treatment of psychiatric disorders, particularly those characterized by emotion dysregulation and anxiety, such as bipolar disorder (Rubia, 2009).

One such question that emerges in relation to this is clearly born out of chapter 3, with the question of whether psychiatric groups would be able to use implementation intentions for emotion regulation, and furthermore whether this would be association with the ‘typical’ pattern of response in right VPC and rVLPFC as the data from chapter 3 suggest are involved in the ‘normal’ functioning of such strategies. There has been some limited work investigating the use of implementation intentions in psychiatric populations. For example, Brandstatter, Langfelder & Gollwitzer (2001) showed that patients with schizophrenia demonstrated improved performance on a go/no-go task when following a relevant implementation intention instruction (“If number 3 appears, I will respond particularly fast!”). This type of study suggests that implementation intentions are capable of being used by patients, and tend to be supportive of the notion that implementation intentions do not necessarily require a high degree of intact executive functioning to be effective (MacFarland & Glisky, 2011). However to date there are no studies that have investigated the use of implementation intention strategies for any aspect of emotional behaviour in patients, and this is therefore a clear future direction that could emerge from the current studies.

Another intriguing possibility that emerges from the thesis arises when taking together the results from chapter 2 and chapter 3. Given that chapter 2 identified dissociable activations that underpin the process of interpersonal emotion regulation, and chapter 3 confirmed the efficacy of implementation intentions for supporting emotion regulation, it may be possible to combine the approaches and use implementation intentions to support the effectiveness of interpersonal emotion regulation.

Such an investigation would be interesting particularly for a number of reasons. First, given the fact that interpersonal functioning and aspects of social cognition such as empathy and theory of mind, shown by the fMRI data in chapter 2 (section 2.7.3, 2.7.4) to be vital to successfully performing interpersonal emotion regulation, are impaired in psychiatric disease such as schizophrenia (Frith, 1992, Collip *et al.,* 2011), any intervention that could be used to promote more successful interpersonal functioning holds promise in being able to manage such deficits in functioning. Second, given that interpersonal emotion regulation is often an effortful process for all individuals (Niven, Totterdell & Holman, 2009, and the behavioral data from chapter 2, section 2.7.1, which support the effortful nature of the process), any intervention that might be able to support these processes in a less effortful fashion may hold promise for a number of individuals, not just those with psychiatric illness. For example, medical practitioners frequently have to engage in interpersonal emotion regulation in order to successfully communicate with patients and their families (Kovacs, Kovacs, & Hegedus, 2010). Crucially they must do this in such a fashion that requires them to demonstrate empathy with the patients but also be able to distance themselves sufficiently in order to ensure that the relevant cognitive resources are available (Decety, Yhang & Chen, 2010), for example either relaying crucial prognostic information accurately to a patient or successfully completing a surgical procedure. There may also be a more general purpose of ensuring ‘self preservation’ by distancing themselves from the deleterious effects of constantly going through the same negative emotion as the patients.

Thirdly, if it was possible that implementation intention were able to promote the execution of ‘pro-social’ behaviours such as interpersonal emotion regulation, it would be of great interest to behavioural scientists and those interested in promotion of pro-social interpersonal functioning, such as policy makers (though as discussed in chapter 2, the reasons and outcome aims for interpersonal emotion regulation may not always be of an altruistic nature, and in fact may be of a selfish nature; Niven, Totterdell & Holman, 2009). Implementation intentions to date have already been, as discussed in chapter 3, section 3.1, used to promote goal-striving and goal achievement in a number of areas (Gollwitzer & Sheeran, 2006) including promotion of dieting (Armitage, 2004) and exercise regimes (Milne, Orbell, & Sheeran, 2002). Implementation intentions have also been shown to promote resistance to, and awareness of ‘risky’ behaviours such as gambling (Webb *at. al.,* 2010) and reduction of binge drinking (Murgraff, White & Phillips, 1996). Although these types of behaviours are associated with facets of interpersonal functioning, the focus to date has primarily been on identification of behaviour within one’s self (and performing an action that is to do with the ‘self’, such as “then I will take a detached perspective”). However it seems plausible that the “then”, goal directed, component of implementation intentions could be directed towards action concerning another person. One possible example as related to emotion regulation might be “If I see someone looking upset, I will make them look at the positive aspects of the situation”.

## 6.5 Limitations of the thesis and future directions

The aims of the thesis were broad in their scope, and although progress has been made in informing our understanding of a number of empirical questions, there are nevertheless limitations to the series of the investigations.

With regards to the investigation of interpersonal emotion regulation, there are still a large number of variables that could be manipulated that might result in different findings in terms of the behavioural or underlying neural correlates. For example this includes a large number of factors with regards to the other person who was the target of the regulation; factors such as gender, relationship to participant, and age, could all have an influence. One recent paper from Lamm, Meltzoff & Decety (2010), however, suggests that the mechanisms of empathy may be broadly similar regardless of whether the other person is similar to the self or not. However future studies could easily manipulate such factors within similar paradigms to investigate this matter. Additionally, as discussed in chapter 2, the paradigm investigates the neural correlates of emotion regulation as executed along similar lines to previous investigations of intrapersonal emotion regulation (i.e. cognitive reappraisal and expressive suppression; Gross, 1998, Goldin *et al.,* 2008). However in everyday life the process of interpersonal emotion regulation does not always occur in this fashion and with this level of co-operation between the protagonists. For example, interpersonal emotion regulation is often not successful in such instances where the ‘stakes’ are much more personally relevant. One example might be a friend unsuccessfully trying to cheer up another friend who has just lost their job. Whereas the nature of the stimuli in the current investigation was undoubtedly aversive in nature, the consequences of not successfully regulating emotional responses to them were not damaging to the participant *per se*. It may be that in instances where the motivation to successfully regulate someone else’s mood is driven by strong motivational factors and has real implications that the process may require even more in the way of social cognition processes such as mentalizing, in order to successfully enact. For example, a friend may have to successfully regulate another friend’s anger in order to avoid getting into a physical conflict.

The investigation into more automatic forms of emotion regulation, such as the fMRI investigation of implementation intentions as described in chapter 3, is also limited by the fact that only one form of automatic emotion regulation was studied. There may be many other ways by which a person might be deemed to be ‘automatically’ regulating their emotion, not all of these amenable to intervention or report due to the fact that they may operate outside of conscious awareness, which is deemed by some to be a critical feature of any automatic emotion regulation process (Mauss *et al.,* 2007). Due to this difficulty in accessing the concept of emotion regulation some studies have even considered automatic emotion regulation to be the process taking place when an individual is presented with material and not given any specific instruction as to how to deal with that material (e.g. Jackson *et al.,* 2003).

However there may be certain forms of automatic emotion regulation that might be more amenable to studying in a similar fashion to the paradigms used in this thesis. One such example might be to investigate the effect of training on a particular emotion regulation strategy over several sessions or days. Currently unpublished data from Christou-Champi *et al.,* (2012), indicates that training over four successive days using a cognitive reappraisal strategy in response to pictures of bodily injuries resulted in reduced physiological arousal, as indexed by heart rate variability, during subsequent passive viewing of bodily injury stimuli. This effect was not present for individuals who had not received any specific training but who had just passively viewed the same number of stimuli, indicating that it was not simply sensitization to the material that was driving the effect. Imaging studies could be well placed to investigate the way, therefore, in which training might support ‘spontaneous’ or ‘automatic’ emotion regulation by looking at neural responses during the subsequent picture viewing task for those who had received training in comparison to those who had not. Such an investigation could also provide a comparison to the present study on implementation intentions described in chapter 3 of this thesis. Specifically, such an investigation would be able to further parse out the contributing components of automatic emotion regulation. Would ‘automatic’ emotion regulation induced by training also enhance mechanisms of attentional control, as seen for implementation intentions? Or is such an effect specific to the nature of implementation intentions in that the presence of the cue word is given increased salience? Future studies could explore these possibilities.

One other issue to emerge from chapter 4 of the thesis, and one that is common to any study of brain stimulation, is to what extent the stimulation that is delivered is acting primarily on the site of stimulation. Although the background to chapter 4 discussed literature suggesting that tDCS does seem to display a neuromodulatory effect upon sites of stimulation (in a polarity dependant fashion; Nitsche *et al.,* 2007), it is nevertheless possible that stimulation may also ‘spread’ to other areas within the cortex, and that this might be mediated by the particular electrode placement montage. For example, Sehm *et al., (*2012) recently reported that unilateral and bilateral tDCS stimulation of motor cortex exhibited dissociable effects on functional connectivity of brain regions following stimulation. It has also recently been reported that the specificity of TMS stimulation is particularly susceptible to individual differences in brain anatomy (particularly in relation to distribution of CSF; Bijsterbosch *et al.,* 2012). Further work is clearly therefore needed to investigate further how tDCS stimulation may be affected by such parameters.

It is also possible that tDCS may have effects beyond that it has on the underlying neuronal population. A recent paper used a computational approach to address the question of whether tDCS stimulation may also have a demonstrable effect upon the glial cells within the brain (Ruohonen & Karhu, 2012). Glial cells play an important role in supporting neuronal functioning in the brain through modulatory and homeostatic processes, and regulation of blood flow (Allen & Baras, 2009). Ruohonen & Karhu demonstrate that tDCS can potentially have an effect on the membrane potential of glial cells in addition to neurons, and that this may help explain some of the pharmacological effects of tDCS (e.g. Stagg *et al.,* 2009) due to the role of the glia in control of neurotransmitters. Further research is necessary to continue to explore the effects of tDCS upon neuronal and glial functioning in order to be able to relate these underlying changes to the observable effects on behaviour and functioning.

## 6.6 Conclusions

The control of one’s own and of other people’s emotions is a complex phenomenon. However studies into the phenomenological and neural basis are beginning to reveal invaluable insights into the mechanisms of how these processes occur, and how they might be affected in clinical disorders.

The studies described in this thesis have contributed towards this burgeoning field by demonstrating that regulating another person’s emotions has a dissociable neural basis from regulating one’s own emotion, demonstrated that strategies for regulating one’s own emotion that differ in their effortful nature are also dissociable on a functional and structural basis, and also demonstrated that the efficacy of emotion regulation can be enhanced through stimulation of areas of the brain known to underpin emotion regulation.

# 7.0 References

Aarts, H., Dijksterhuis, A., Midden, C. (1999). To plan or not to plan? Goal achievement or interrupting the performance of mundane behaviors. European Journal of Social Psychology, 29, 971–979.

Adolphs, R. (2010). What does the amygdala contribute to social cognition? Annals of the New York Academy of Sciences, 1191, 42-61.

Allen, N.J., Barres, B.A. (2009). Glia - more than just brain glue. Nature, 457, 675–677.

Almeida, J.R.C., Mechelli, A., Hassel, S., Versace, A., Kupfer, D.J., Phillips, M.L. (2009). Abnormally increased effective connectivity between parahippocampal gyrus and ventromedial prefrontal regions during emotion labeling in bipolar disorder. Psychiatry Research: Neuroimaging, 174, 195-201.

Amodio, D.M., Frith, C.D. (2006). Meeting of minds: the medial frontal cortex and social cognition. Nature Reviews Neuroscience, 7, 268–277.

Armitage, C.J. (2004). Evidence that implementation intentions reduce dietary fat intake: a randomized trial. Health Psychology, 23, 319–23.

Ashburner, J. (2007). A fast diffeomorphic image registration algorithm. NeuroImage, 38, 95–113.

Ashburner, J., Friston, K.J. (2000). Voxel-based morphometry--the methods. NeuroImage, 11, 805–821.

Badre, D., Wagner, A.D. (2007). Left ventrolateral prefrontal cortex and the cognitive control of memory. Neuropsychologia, 45, 2883–2901.

Banks, S.J., Eddy, K.T., Angstadt, M., Nathan, P.J., Phan, K.L. (2007). Amygdala-frontal connectivity during emotion regulation. Social Cognitive and Affective Neuroscience, 2, 303-312.

Barbey, A.K., Koenigs, M., Grafman, J. (2013). Dorsolateral prefrontal contributions to human working memory. Cortex, 49, 1195–1205.

Bargh, J.A., Chartrand, T.L. (1999). The unbearable automaticity of being. American Psychologist, 54, 462–479.

Beauregard, M, Levesque, J., Bourgouin, P. (2001). Neural correlates of conscious self-regulation of emotion. The Journal of Neuroscience, 21, 165-171.

Beauregard, M., Paquette, V., Levesque, J. (2006). Dysfunction in the neural circuitry of emotional self-regulation in major depressive disorder. NeuroReport, 17, 843-846.

Beedie, C.J., Terry, P.C., Lane, A.M. (2005). Distinguishing mood from emotion. Cognition and Emotion, 19, 847-878.

Beer, J.S, John, O.P., Scabini, D., Knight, R.T. (2006). Orbitofrontal cortex and social behaviour: integrating self-monitoring and emotion-cognition interactions. Journal of Cognitive Neuroscience, 18, 871-879.

Benedek, M., Kaernbach, C. (2010). A continuous measure of phasic electrodermal activity. Journal of Neuroscience Methods, 190, 80-91.

Benoit, R. G., Gilbert, S. J, Volle, E., Burgess, P.W. (2010). When I think about me and simulate you: Medial rostral prefrontal cortex and self-referential processes. NeuroImage, 50, 1340-1349.

Berking, M., Wupperman, P., Reichardt, A., Pejic, T., Dippel, A., Znoj, H. (2008). Emotion-regulation skills as a treatment target in psychotherapy. Behaviour Research and Therapy, 46, 1230-1237.

Bermpohl, F., Pascual-Leone, A., Amedi, A., Merabet, L.B., Fregni, F., Gaab, N., Alsop, D., Schlaug, G., Northoff, G. (2006). Dissociable networks for the expectancy and perception of emotional stimuli in the human brain. NeuroImage, 30, 588-600.

Bijsterbosch, J.D., Barker, A.T., Lee, K.-H., Woodruff, P.W.R., (2012). Where does transcranial magnetic stimulation (TMS) stimulate? Modelling of induced field maps for some common cortical and cerebellar targets. Medical & Biological Engineering & Computing 50, 671–681.

Boggio, P.S., Rigonatti, S.P., Ribeiro, R.B., Myczkowski, M.L., Nitsche, M.A., Pascual-Leone, A. Fregni, F. (2008). A randomized, double-blind clinical trial on the efficacy of cortical direct current stimulation for the treatment of major depression. International Journal of Neuropsychopharmacology, 11, 249-254.

Boggio, P.S., Zaghi, S., Fregni, F. (2009). Modulation of emotions associated with images of human pain using anodal transcranial direct current stimulation (tDCS). Neuropsychologia, 47, 212-217.

Brandstaetter, V., Lengfelder, A., Gollwitzer, P.M. (2001). Implementation intentions and efficient action initiation. Journal of Personality and Social Psychology, 81, 946-960.

Bruen, P.D., McGeown, W.J., Shanks, M.F., Venneri, A. (2008). Neuroanatomical correlates of neuropsychiatric symptoms in Alzheimer’s disease. Brain, 131, 2455–2463.

Brunelin, J., Mondino, M., Gassab, L., Haesebaert, F., Gaha, L., Suaud-Chagny, M.-F., Saoud, M., Mechri, A., Poulet, E. (2012). Examining transcranial direct-current stimulation (tDCS) as a treatment for hallucinations in schizophrenia. The American Journal of Psychiatry, 169, 719–724.

Burgess, P.W., Dumontheil, I., Gilbert, S.J. (2007). The gateway hypothesis of rostral prefrontal cortex (area 10) function. Trends in Cognitive Sciences, 11, 290–298.

Bush, G., Luu, P., & Posner, M.I. (2000). Cognitive and emotional influences in anterior cingulate cortex. Trends in Cognitive Sciences, 4, 215–222.

Cabeza, R., Ciaramelli, E., Moscovitch, M. (2012). Cognitive contributions of the ventral parietal cortex: an integrative theoretical account. Trends in Cognitive Sciences, 16, 338–352.

Cahill, L. (2006). Why sex matters for neuroscience. Nature Reviews Neuroscience, 7, 477-484.

Campbell-Sills, L., Barlow, D.H., Brown, T.A., Hofmann, S.G. (2006). Effects of suppression and acceptance on emotional responses of individuals with anxiety and mood disorders. Behaviour Research and Therapy, 44, 1251-1263.

Campbell-Sills., L, Barlow D.H. (2007). Incorporating emotion regulation into conceptualizations and treatments of anxiety and mood disorders. In: Gross, J.J., (ed). Handbook of Emotion Regulation, pp. 542–559, New York: Guilford Press.

Campbell-Sills, L., Simmons, A.N., Lovero, K.L., Rochlin, A.A, Paulus, M.P., Stein, M.B. (2010). Functioning of neural systems supporting emotion regulation in anxiety-prone individuals. NeuroImage, 54, 689-696.

Caseras, X., Mataix-Cols, D., Lawrence, N.S., Speckens, A., Giampietro, V., Brammer, M.J., Phillips, M.L. (2007). Sex differences in neural responses to disgusting visual stimuli: Implications for disgust-related psychiatric disorders. Biological Psychiatry, 62, 464–471.

Cassidy, J. (1994). Emotion regulation: Influences of attachment relationships. Monographs of the Society for Research in Child Development, 59, 228–249.

Cohen Kadosh, R., Soskic, S., Iuculano, T., Kanai, R., Walsh, V. (2010). Modulating Neuronal Activity Produces Specific and Long-Lasting Changes in Numerical Competence. Current Biology, 20, 2016–2020.

Collip, D., Wigman, J.T.W., Lin, A., Nelson, B., Oorschot, M., Vollebergh, W.A.M., Ryan, J., Baksheev, G., Wichers, M., Van Os, J., Myin-Germeys, I., Yung, A.R. (2011). Dynamic association between interpersonal functioning and positive symptom dimensions of psychosis over time: a longitudinal study of healthy adolescents. Schizophrenia Bulletin sbr115–.

**Consedine, N.S., Yu, W, T-C., Windsor, J. (2013). Nursing, pharmacy, or medicine? Disgust sensitivity predicts career interest among trainee health professionals. Advances in Health Science Education. E-pub: 11th Jan 2013.**

Cooney, R.E., Joormann, J., Eugène, F., Dennis, E.L., Gotlib, I.H. (2010). Neural correlates of rumination in depression. Cognitive, Affective, and Behavioral Neuroscience, 10, 470–478.

Craig, A.D.B. (2009). How do you feel--now? The anterior insula and human awareness. Nature Reviews Neuroscience, 10, 59–70.

Critchley, H.D., Mathias, C.J., Josephs, O., O’Doherty, J., Zanini, S., Dewar, B.-K., Cipolotti, L., Shallice, T., Dolan, R.J. (2003). Human cingulate cortex and autonomic control: converging neuroimaging and clinical evidence. Brain, 126, 2139–2152.

Curtis, C.E., D’Esposito, M. (2003). Persistent activity in the prefrontal cortex during working memory. Trends in Cognitive Sciences, 7, 415–423.

Dan-Glauser, E.S., Gross, J.J. (2011). The temporal dynamics of two response-focused forms of emotion regulation: Experiential, expressive, and autonomic consequences. Psychophysiology, 48, 1309–1322.

Davidson, R.J, Putman, K.M., Larson, C.L. (2000). Dysfunction in the neural circuitry of emotion regulation - a possible prelude to violence. Science, 289, 591-594.

Davis, J.I., Gross, J.J., Ochsner, K.N. (2011). Psychological distance and emotional experience: What you see is what you get. Emotion, 11, 438–444.

Daw, N.D., O’Doherty, J.P., Dayan, P., Seymour, B., Dolan, R.J. (2006). Cortical substrates for exploratory decisions in humans. Nature, 441, 876–879.

Decety, J., Chaminade, T. (2003). Neural correlates of feeling sympathy. Neuropsychologia, 41, 127-138.

Decety, J., Yang, C.-Y., Cheng, Y. (2010). Physicians down-regulate their pain empathy response: an event-related brain potential study. NeuroImage, 50, 1676–1682.

Decety, J., Lamm, C. (2007). The role of the right temporoparietal junction in social interaction: How low-level computational processes contribute to meta-cognition. The Neuroscientist, 13, 580–593.

Devinsky, O., Morrell, M. J., & Vogt, B. A. (1995). Contributions of anterior cingulate cortex to behaviour. Brain, 118, 279–306.

Dillon, D.G., LaBar, K.S. (2005). Startle Modulation During Conscious Emotion Regulation Is Arousal-Dependent. Behavioral Neuroscience, 119, 1118-1124.

Dmochowski, J.P., Datta, A., Bikson, M., Su, Y., Parra, L.C., (2011). Optimized multi-electrode stimulation increases focality and intensity at target. Journal of Neural Engineering, 8, 046011.

Dockery, C.A., Hueckel-Weng, R., Birbaumer, N., Plewnia, C. (2009). Enhancement of planning ability by transcranial direct current stimulation. The Journal of Neuroscience, 29, 7271–7277.

Domes, G., Schulze, L., Böttger, M., Grossmann, A., Hauenstein, K., Wirtz, P.H., Heinrichs, M., Herpertz, S. (2009). The neural correlates of sex differences in emotional reactivity and emotion regulation. Human Brain Mapping, 31, 758-769.

Drabant, E.M., McRae, K., Manuck, S.B., Hariri, A.R., Gross, J.J. (2008). Individual differences in typical reappraisal use predict amygdala and prefrontal responses. Biological Psychiatry, 65, 367-373.

Driscoll, D., Tranel, D., Anderson, S.W. (2009). The effects of voluntary regulation of positive and negative emotion on psychophysiological responsiveness. International Journal of Psychophysiology, 72, 61-66.

Ehring, T., Tuschen-Caffier, B., Schnülle, J., Fischer, S., Gross, J.J. (2010). Emotion regulation and vulnerability to depression: Spontaneous versus instructed use of emotion suppression and reappraisal. Emotion, 10, 563–572.

Eippert, F., Veit, R., Weiskopf, N., Erb, M., Birbaumer, N., Anders, S. (2007). Regulation of emotional responses elicited by threat-related stimuli. Human Brain Mapping, 28, 409-423.

Eisenberger, N. I., Lieberman, M.D. (2004). Why rejection hurts: a common neural alarm system for physical and social pain. Trends in Cognitive Sciences, 8, 294–300.

Ekman, P., Levenson, R.W., Friesen, W.V, (1983). Autonomic nervous system activity distinguishes among emotions. Science, 221, 1208–1210.

Elliott, R., Dolan, R.J., Frith, C.D. (2000). Dissociable Functions in the Medial and Lateral Orbitofrontal Cortex: Evidence from Human Neuroimaging Studies. Cerebral Cortex, 10, 308–317.

Erber, R., Wegner, D.M., Therriault, N. (1996). On being cool and collected: mood regulation in anticipation of social interaction., Journal of Personality and Social Psychology, 70, 757-766.

Etkin, A., Prater, K.E., Hoeft, F., Menon, V., Schatzberg, A.F. (2010). Failure of anterior cingulate activation and connectivity with the amygdala during implicit regulation of emotional processing in generalized anxiety disorder. The American Journal of Psychiatry, 167, 545-554.

Eysenck, S.B.G., Eysenck, H.J., Barrett, P. (1985). A revised version of the psychoticism scale. Personality and Individual Differences, 6, 21–29.

Fales, C.L., Barch, D.M., Rundle, M.M., Mintun, M.A., Snyder, A.Z., Cohen, J.D., Matthews, J., Sheline, Y.I. (2008). Altered emotional interference processing in affective and cognitive-control brain circuitry in major depression. Biological Psychiatry, 63, 377-384.

Farrow, T.F.D., Zheng, Y., Wilkinson, I.D., Spence, S.A., Deakin, J.F.W., Tarrier, N., Griffiths, P.D., Woodruff, P.W.R. (2001). Investigating the functional anatomy of empathy and forgiveness. NeuroReport, 12, 2433–2438.

Farrow, T.F.D., Johnson, N.K., Hunter, M.D., Barker, A.T., Wilkinson, I.D., Woodruff, P.W.R. (2012). Neural correlates of the behavioral-autonomic interaction response to potentially threatening stimuli. Frontiers in Human Neuroscience, 6, 349.

Fecteau, S., Knoch, D., Fregni, F., Sultani, N., Boggio, P., Pascual-Leone, A. (2007a). Diminishing risk-taking behavior by modulating activity in the prefrontal cortex: a direct current stimulation study. Journal of Neuroscience, 27, 12500–12505.

Fecteau, S., Pascual-Leone, A., Zald, D.H., Liguori, P., Théoret, H., Boggio, P.S., Fregni, F. (2007b). Activation of prefrontal cortex by transcranial direct current stimulation reduces appetite for risk during ambiguous decision making. Journal of Neuroscience, 27, 6212–6218.

Feinstein, J.S., Duff, M.C., Tranel, D. (2010). Sustained experience of emotion after loss of memory in patients with amnesia. Proceedings of the National Academy of Sciences of the United States of America, 107, 7674-7679.

Ferreira, L.K., Diniz, B.S., Forlenza, O.V, Busatto, G.F., Zanetti, M.V. (2011). Neurostructural predictors of Alzheimer’s disease: a meta-analysis of VBM studies. Neurobiology of Aging, 32, 1733–1741.

Fertonani, A., Rosini, S., Cotelli, M., Rossini, P.M., Miniussi, C. (2010). Naming facilitation induced by transcranial direct current stimulation. Behavioural Brain Research, 208, 311–318.

Fischer, A.H., Van Kleef, G.A. (2010). Where Have All the People Gone? A Plea for Including Social Interaction in Emotion Research. Emotion Review, 2, 208–211.

Foland, L.C., Altshuler, L.L., Bookheimer, S.Y., Eisenberger, N., Townsend, J., Thompson, P.M. (2008). Evidence for deficient modulation of amygdala response by prefrontal cortex in bipolar mania. Psychiatry Research: Neuroimaging, 162, 27-37.

Freed, P.J., Yanagihara, T.K., Hirsch, J., Mann, J.J. (2009). Neural mechanisms of grief regulation. Biological Psychiatry, 66, 33-40.

Fregni, F., Boggio, P.S., Nitsche, M.A., Marcolin, M.A., Rigonatti, S.P., Pascual-Leone, A. (2006). Treatment of major depression with transcranial direct current stimulation. Bipolar Disorders, 8, 203-204.

Friston, K.J., Buechel, C., Fink, G.R., Morris, J., Rolls, E., Dolan, R.J. (1997). Psychophysiological and modulatory interactions in neuroimaging. NeuroImage 6, 218–229.

Frith, C., Allen, H. (1983). The skin conductance orienting response as an index of attention. Biological Psychology, 17, 27–39.

Frith, C.D. (1992). The cognitive neuropsychology of schizophrenia. Lawrence Erlbaum Associates, Hove: UK

Frith, U., Frith, C.D. (2003). Development and neurophysiology of mentalizing. Philosophical Transactions of the Royal Society B Biological Sciences, 358, 459–473.

Fulwiler, C.E., King, J.A., Zhang, N. (2012). Amygdala-orbitofrontal resting-state functional connectivity is associated with trait anger. NeuroReport, 23, 606–610.

Gallagher, H.L., Happé, F., Brunswick, N., Fletcher, P.C., Frith, U., Frith, C.D. (2000). Reading the mind in cartoons and stories: an fMRI study of “theory of mind” in verbal and nonverbal tasks. Neuropsychologia, 38, 11-21.

Gallagher, H.L., Frith, C.D. (2003). Functional imaging of “theory of mind”. Trends in Cognitive Sciences, 7, 77–83.

Gallo, I.S., McCulloch, K.C., Gollwitzer, P.M. (2012). Differential Effects of Various Types of Implementation Intentions on the Regulation of Disgust. Social Cognition, 30, 1–17

Gard, M.G., Kring, A.M. (2007). Sex differences in the time course of emotion. Emotion, 7, 429-437.

Gilbert, S.J., Gollwitzer, P.M., Cohen, A.-L., Burgess, P.W., Oettingen, G. (2009). Separable brain systems supporting cued versus self-initiated realization of delayed intentions. Journal of Experimental Psychology. Learning, Memory, and Cognition, 35, 905–915.

Gillath, O., Bunge, S.A., Shaver, P.R., Wendelken, C., Mikulincer, M. (2005). Attachment-style differences in the ability to suppress negative thoughts: exploring the neural correlates. NeuroImage, 28, 835-847.

Giorgio, A., Santelli, L., Tomassini, V., Bosnell, R., Smith, S., De Stefano, N., Johansen-Berg, H. (2010). Age-related changes in grey and white matter structure throughout adulthood. NeuroImage, 51, 943–951.

Giuliani, N.R., Drabant, E.M., Gross, J.J., (2011). Anterior cingulate cortex volume and emotion regulation: is bigger better? Biological Psychology, 86, 379–382.

Giuliani, N.R., Drabant, E.M., Bhatnagar, R., Gross, J.J. (2011). Emotion regulation and brain plasticity: Expressive suppression use predicts anterior insula volume. NeuroImage, 58, 10–15.

Goldin, P.R., McRae, K., Ramel, W., Gross, J.J. (2008). The neural bases of emotion regulation: reappraisal and suppression of negative emotion. Biological Psychiatry, 63, 577-586.

Goldin, P.R., Manber-Ball, T., Werner, K., Heimberg, R., Gross, J.J. (2009). Neural Mechanisms of Cognitive Reappraisal of Negative Self-Beliefs in Social Anxiety Disorder. Biological Psychiatry, 66, 1091-1099.

Golkar, A., Lonsdorf, T.B., Olsson, A., Lindstrom, K.M., Berrebi, J., Fransson, P., Schalling, M., Ingvar, M., Öhman, A. (2012). Distinct contributions of the dorsolateral prefrontal and orbitofrontal cortex during emotion regulation. PLoS ONE, 7, e48107.

Gollwitzer, P.M. (1993). Goal achievement: The role of intentions. European Review of Social Psychology, 4, 141–185.

Gollwitzer, P.M., Sheeran, P. (2006). Implementation intentions and goal achievement: A meta-analysis of effects and processes. Advances in Experimental Social Psychology, 38, 69–119

Greenwald, A.G., McGhee, D.E., Schwartz, J.L. (1998). Measuring individual differences in implicit cognition: the implicit association test. Journal of Personality and Social Psychology, 74, 1464–1480.

Greenwald, A.G., Farnham, S.D. (2000). Using the implicit association test to measure self-esteem and self-concept. Journal of Personality and Social Psychology, 79, 1022–1038.

Greenwald, A.G., Nosek, B.A., Banaji, M.R. (2003). Understanding and using the implicit association test: I. An improved scoring algorithm. Journal of Personality and Social Psychology, 85, 197–216.

Grosbras, M.-H., Laird, A.R., Paus, T. (2005). Cortical regions involved in eye movements, shifts of attention, and gaze perception. Human Brain Mapping, 25, 140–154.

Gross, J.J. (1998). The emerging field of emotion regulation: an integrative review. Review of General Psychology, 2, 271-299.

Gross, J.J. (2002). Emotion regulation: affective, cognitive, and social consequences. Psychophysiology, 39, 281-291.

Gross, J.J., Levenson, R.W. (1997). Hiding feelings: the acute effects of inhibiting negative and positive emotion. Journal of Abnormal Psychology, 106, 95–103.

Gross, J.J., John, O.P. (2003). Individual differences in two emotion regulation processes: Implications for affect, relationships, and well-being. Journal of Personality and Social Psychology, 85, 348-362.

Gross, J.J., Thompson, R.A. (2007). Emotion regulation: Conceptual foundations. In J.J. Gross (Ed.), Handbook of Emotion Regulation, pp. 3-24. Guilford Press: New York

Gruber, O., Von Cramon, D.Y. (2003). The functional neuroanatomy of human working memory revisited. Evidence from 3-T fMRI studies using classical domain-specific interference tasks. NeuroImage, 19, 797–809.

Hamann, S., Canli, T. (2004). Individual differences in emotion processing. Current Opinion in Neurobiology, 14, 233-238.

Hampshire, A., Chamberlain, S.R., Monti, M.M., Duncan, J., Owen, A.M. (2010). The role of the right inferior frontal gyrus: inhibition and attentional control. NeuroImage, 50, 1313–1319.

Hare, T.A., Tottenham, N., Galvan, A., Voss, H.U., Glover, G.H., Casey, B.J. (2008). Biological substrates of emotional reactivity and regulation in adolescence during an emotional go-nogo task. Biological Psychiatry, 63, 927-934.

Harenski, C.L., Hamann, S. (2006). Neural correlates of regulating negative emotions related to moral violations. Neuroimage, 30, 313-324.

Harenski, C.L., Kim, S.H., Hamann, S. (2009). Neuroticism and psychopathy predict brain activation during moral and nonmoral emotion regulation. Cognitive, Affective, & Behavioral Neuroscience, 9, 1-15.

Harlow, J.M. (1993). Recovery from the passage of an iron bar through the head. History of Psychiatry, 4, 274–281.

Haut, K.M., Lim, K.O., Macdonald, A. (2010). Prefrontal cortical changes following cognitive training in patients with chronic schizophrenia: effects of practice, generalization, and specificity. Neuropsychopharmacology, 35, 1850-1859.

Henson, R.N., Burgess, N., Frith, C.D. (2000). Recoding, storage, rehearsal and grouping in verbal short-term memory: an fMRI study. Neuropsychologia, 38, 426–440.

Hermann, A., Schäfer, A., Walter, B., Stark, R., Vaitl, D., Schienle, A. (2009). Emotion regulation in spider phobia: role of the medial prefrontal cortex. Social Cognitive and Affective Neuroscience, 4, 257-267.

Herwig, U., Kaffenberger, T., Baumgartner, T., Jancke, L. (2006). Neural correlates of a “pessimistic” attitude when anticipating events of unknown emotional valence. NeuroImage, 34, 848-858.

Herwig, U., Baumgartner, T., Kaffenberger, T., Brühl, A., Kottlow, M., Schreiter-Gasser, U., Abler, B., Jäncke, L., Rufer, M. (2007). Modulation of anticipatory emotion and perception processing by cognitive control. NeuroImage, 37, 652-662.

Hölzel, B. K., Carmody, J., Vangel, M., Congleton, C., Yerramsetti, S. M., Gard, T., Lazar, S. W. (2011). Mindfulness practice leads to increases in regional brain gray matter density. Psychiatry Research, 191, 36–43.

Hooker, C.I., Verosky, S.C., Germine, L.T., Knight, R.T., D’Esposito, M. (2010). Neural activity during social signal perception correlates with self-reported empathy. Brain Research, 1308, 100–113.

Hortensius, R., Schutter, D.J.L.G., Harmon-Jones, E. (2012). When anger leads to aggression: induction of relative left frontal cortical activity with transcranial direct current stimulation increases the anger-aggression relationship. Social Cognitive and Affective Neuroscienceognitive and affective neuroscience, 7, 342–347.

Izard, C.E. (2010). The Many Meanings/Aspects of Emotion: Definitions, Functions, Activation, and Regulation. Emotion Review, 2, 363–370.

Jackson D.C., Mueller, C.J., Dolski, I., Dalton, K.M., Nitschke, J.B., Urry, H.L., Rosenkranz, M.A., Ryff, C.D., Singer, B.H., Davidson, R.J. (2003). Now you feel it, now you don’t: frontal brain electrical asymmetry and individual differences in emotion regulation. Psychological Science, 14, 612–617.

Jackson, P.L., Decety, J. (2004). Motor cognition: a new paradigm to study self-other interactions. Current Opinion in Neurobiology, 14, 259–263.

Jackson, P.L., Brunet, E., Meltzoff, A.N., Decety, J. (2006). Empathy examined through the neural mechanisms involved in imagining how I feel versus how you feel pain. Neuropsychologia, 44, 752-761.

Jimura, K., Konishi, S., Asari, T., Miyashita, Y. (2010). Temporal pole activity during understanding other persons’ mental states correlates with neuroticism trait. Brain Research, 1328, 104–112.

Johnstone, T.,van Reekum, C.M., Urry, H.L., Kalin, N.H., Davidson, R.J. (2007). Failure to regulate: counterproductive recruitment of top-down prefrontal-subcortical circuitry in major depression. The Journal of Neuroscience, 27, 8877-8884.

Kalisch, R. (2009). The functional neuroanatomy of reappraisal: time matters. Neuroscience & Biobehavioral Reviews, 33, 1215-1226.

Kennedy, D.P., Gläscher, J., Tyszka, J.M., Adolphs, R., (2009). Personal space regulation by the human amygdala. Nature Neuroscience, 12, 1226–1227.

Kilpatrick, L.A., Zald, D.H., Pardo, J.V., Cahill, L.F. (2006). Sex-related differences in amygdala functional connectivity during resting conditions. NeuroImage, 30, 452-461.

Kim, S.H., Hamann, S. (2007). Neural correlates of positive and negative emotion regulation. Journal of Cognitive Neuroscience, 19, 776-798.

Kober, H., Mende-Siedlecki, P., Kross, E.F., Weber, J., Mischel, W., Hart, C.L., Ochsner, K.N. (2010). Prefrontal-striatal pathway underlies cognitive regulation of craving. Proceedings of the National Academy of Sciences of the United States of America, 107, 14811-14816.

Koch, K., Pauly, K., Kellermann, T., Seiferth, N.Y., Reske, M., Backes, V., Stöcker, T., Shah, N.J., Amunts, K., Kircher, T., Schneider, F., Habel, U. (2007). Gender differences in the cognitive control of emotion: An fMRI study. Neuropsychologia, 45, 2744–2754.

Kovács, M., Kovács, E., Hegedűs, K. (2010). Emotion work and burnout: cross-sectional study of nurses and physicians in Hungary. Croatian Medical Journal, 51, 432–442.

Kringelbach, M.L. (2005). The human orbitofrontal cortex: linking reward to hedonic experience. Nature Reviews Neuroscience, 6, 691–702.

Kroese, F.M., Adriaanse, M.A., Evers, C., De Ridder, D.T.D. (2011). “Instant success”: turning temptations into cues for goal-directed behavior. Personality and Social Psychology Bulletin, 37, 1389–1397.

Kross, E. Davidson, M., Weber, J., Ochsner, K.N. (2009). Coping with emotions past: The neural bases of regulating affect associated with negative autobiographical memories. Biological Psychiatry, 65, 361-366.

Kübler, A., Dixon, V., & Garavan, H. (2006). Automaticity and reestablishment of executive control-an fMRI study. Journal of Cognitive Neuroscience, 18, 1331–1342.

Kühn, S., Müller, B.C.N., Van der Leij, A., Dijksterhuis, A., Brass, M., Van Baaren, R.B. (2011). Neural correlates of emotional synchrony. Social Cognitive and Affective Neuroscience, 6, 368–74.

Kühn, S., Gallinat, J., Brass, M., (2011). “Keep calm and carry on”: structural correlates of expressive suppression of emotions. PLoS ONE, 6, e16569.

Lamm, C., Meltzoff, A.N., Decety, J. (2010). How do we empathize with someone who is not like us? A functional magnetic resonance imaging study. Journal of Cognitive Neuroscience, 22, 362–376.

Lang, P.J., Bradley, M.M., Cuthbert, B.N. (2005). International affective picture system (IAPS): affective ratings of pictures and instruction manual. Technical Report A-6. Gainesville, FL: University of Florida.

Lee, K.-H., Brown, W.H., Egleston, P.N., Green, R.D.J., Farrow, T.F.D., Hunter, M.D., Parks, R.W., Wilkinson, I.D., Spence, S.A., Woodruff, P.W.R. (2006). A functional magnetic resonance imaging study of social cognition in schizophrenia during an acute episode and after recovery. The American Journal of Psychiatry, 163, 1926–1933.

Lee, K.-H., Farrow, T.F.D., Spence, S.A., Woodruff, P.W.R. (2004). Social cognition, brain networks and schizophrenia. Psychological Medicine, 34, 391-400.

Levesque, J., Eugene, F., Joanette, Y., Paquette, V., Mensour, B., Beaudoin, G., Leroux, J. Bourgouin, P., Beauregard, M. (2003). Neural circuitry underlying voluntary suppression of sadness. Biological Psychiatry, 53, 502-510.

Levesque, J., Joanette, Y., Mensour, B., Beaudoin, G., Leroux, L. M., Bourgouin, P., Beauregard, M. (2004). Neural basis of emotional self-regulation in childhood. Neuroscience, 129, 361-369.

Levin, R., Nielsen, T. (2009). Nightmares, bad dreams, and emotion dysregulation: A review and new neurocognitive model of dreaming. Current Directions in Psychological Science, 18, 84-88.

Levita, L., Hare, T.A., Voss, H.U., Glover, G., Ballon, D.J., Casey, B.J., (2009). The bivalent side of the nucleus accumbens. NeuroImage, 44, 1178–1187.

Levita, L., Hoskin, R., Champi, S., (2012). Avoidance of harm and anxiety: A role for the nucleus accumbens. NeuroImage, 62, 189–198.

Levy, B.J., Wagner, A.D. (2011). Cognitive control and right ventrolateral prefrontal cortex: reflexive reorienting, motor inhibition, and action updating. Annals of the New York Academy of Sciences, 1224, 40–62.

Lieberman, M.D., Eisenberger, N.I., Crockett, M.J., Tom, S.M., Pfeifer, J.H., & Way, B.M. (2007). Putting feelings into words: affect labeling disrupts amygdala activity in response to affective stimuli. Psychological Science, 18, 421–428

Lieberman, M.D., Cunningham, W.A. (2009). Type I and Type II error concerns in fMRI research: re-balancing the scale. Social Cognitive and Affective Neuroscience, 4, 423–428.

Loo, C.K., Sachdev, P., Martin, D., Pigot, M., Alonzo, A., Malhi, G.S., Lagopoulos, J., Mitchell, P. (2010). A double-blind, sham-controlled trial of transcranial direct current stimulation for the treatment of depression. The International Journal of Neuropsychopharmacology, 13, 61–99.

Lou, H.C., Luber, B., Crupain, M., Keenan, J.P., Nowak, M., Kjaer, T.W., Sackeim, H. a, Lisanby, S.H. (2004). Parietal cortex and representation of the mental Self. Proceedings of the National Academy of Sciences of the United States of America, 101, 6827–32.

Luders, E., Toga, A.W., Lepore, N., Gaser, C. (2009). The underlying anatomical correlates of long-term meditation: larger hippocampal and frontal volumes of gray matter. NeuroImage, 45, 672-678.

McCormick, D.A. (1989). GABA as an inhibitory neurotransmitter in human cerebral cortex. Journal of Neurophysiology, 62, 1018–1027.

McFarland, C.P., Glisky, E.L. (2011). Implementation intentions and prospective memory among older adults: an investigation of the role of frontal lobe function. Neuropsychology, Development, and Cognition, 18, 633–652.

Mak, A.K.Y., Hu, Z., Zhang, J.X., Xiao, Z., Lee, T.M.C. (2009a). Neural correlates of regulation of positive and negative emotions: an fMRI study. Neuroscience Letters, 457, 101-106.

Mak, A. K.Y., Hu, Z., Zhang, J.X., Xiao, Z., Lee, T.M.C. (2009b). Sex-related differences in neural activity during emotion regulation. Neuropsychologia, 47, 2900-2908.

Maldjian, J.A., Laurienti, P.J., Kraft, R.A., Burdette, J.H. (2003). An automated method for neuroanatomic and cytoarchitectonic atlas-based interrogation of fMRI data sets. NeuroImage 19, 1233– 1239

Margulies, D.S., Kelly, A.M.C., Uddin, L.Q., Biswal, B.B., Castellanos, F.X., & Milham, M.P. (2007). Mapping the functional connectivity of anterior cingulate cortex. NeuroImage, 37, 579–588.

Mauss, I.B., Evers, C., Wilhelm, F.H., Gross, J.J. (2006). How to bite your tongue without blowing your top: implicit evaluation of emotion regulation predicts affective responding to anger provocation. Personality and Social Psychology Bulletin, 32, 589–602.

Mauss, I.B., Bunge, S.A., Gross, J.J. (2007). Automatic Emotion Regulation. Social and Personality Psychology Compass, 1, 146-167.

McRae, K, Ochsner, K.N., Mauss, I.B., Gabrieli, J. J. D., Gross, J.J. (2008). Gender differences in emotion regulation: An fMRI study of cognitive reappraisal, 11, 143-162.

McRae, K., Hughes, B., Chopra, S., Gabrieli, J.D. E., Gross, J. J., Ochsner, K.N. (2010). The neural bases of distraction and reappraisal. Journal of Cognitive Neuroscience, 22, 248-262.

Merzagora, A.C., Foffani, G., Panyavin, I., Mordillo-Mateos, L., Aguilar, J., Onaral, B., Oliviero, A. (2010). Prefrontal hemodynamic changes produced by anodal direct current stimulation. NeuroImage, 49, 2304–2310.

Mikels, J.A., Fredrickson, B.L., Larkin, G.R., Lindberg, C.M., Maglio, S.J., Reuter-Lorenz, P.A., (2005). Emotional category data on images from the International Affective Picture System. Behavior Research Methods, 37, 626–630.

Milne, S., Orbell, S., Sheeran, P., (2002). Combining motivational and volitional interventions to promote exercise participation: protection motivation theory and implementation intentions. British Journal of Health Psychology, 7, 163–168.

Mitchell, D.G.V., Nakic, M., Fridberg, D., Kamel, N., Pine, D.S., Blair, R.J.R. (2007). The impact of processing load on emotion. NeuroImage, 34, 1299-1309.

Moses-Kolko, E.L., Perlman, S.B., Wisner, K.L., James, J., Saul, A.T., Phillips, M.L. (2010). Abnormally reduced dorsomedial prefrontal cortical activity and effective connectivity with amygdala in response to negative emotional faces in postpartum depression. The American Journal of Psychiatry, 167, 1373-1380.

Mühlberger, A., Neumann, R., Wieser, M.J., Pauli, P., (2008). The impact of changes in spatial distance on emotional responses. Emotion, 8, 192–198.

Murgraff, V., White, D., Phillips, K. (1996). Moderating binge drinking: it is possible to change behaviour if you plan it in advance. Alcohol and Alcoholism, 31, 577–582.

New, A.S., Fan, J., Murrough, J.W., Liu, X., Liebman, R.E., Guise, K.G., Tang, C.Y., Charney, D.S. (2009). A Functional Magnetic Resonance Imaging Study of Deliberate Emotion Regulation in Resilience and Posttraumatic Stress Disorder. Biological Psychiatry, 66, 656-664.

Nili, U., Goldberg, H., Weizman, A., Dudai, Y. (2010). Fear thou not: activity of frontal and temporal circuits in moments of real-life courage. Neuron, 66, 949-962.

Nitsche, M.A., Paulus, W. (2000). Excitability changes induced in the human motor cortex by weak transcranial direct current stimulation. The Journal of Physiology, 527, 633–639.

Nitsche, M.A., Fricke, K., Henschke, U., Schlitterlau, A., Liebetanz, D., Lang, N., Henning, S., Tergau, F., Paulus, W. (2003). Pharmacological modulation of cortical excitability shifts induced by transcranial direct current stimulation in humans. The Journal of Physiology 553, 293–301.

Nitsche, M.A., Doemkes, S., Karaköse, T., Antal, A., Liebetanz, D., Lang, N., Tergau, F., Paulus, W. (2007). Shaping the effects of transcranial direct current stimulation of the human motor cortex. Journal of Neurophysiology, 97, 3109–3117.

Nitsche, M. A., Boggio, P. S., Fregni, F., Pascual-Leone, A. (2009). Treatment of depression with transcranial direct current stimulation (tDCS): a review. Experimental Neurology, 219, 14–19.

Niven, K., Totterdell, P., Holman, D. (2009). A classification of controlled interpersonal affect regulation strategies. Emotion, 9, 498-509.

Nosek, B.A., Banaji, M.R., Greenwald, A.G. (2002). Math = male, me = female, therefore math not = me. Journal of Personality and Social Psychology, 83, 44–59.

O’Doherty, J., Dayan, P., Schultz, J., Deichmann, R., Friston, K., Dolan, R.J. (2004). Dissociable roles of ventral and dorsal striatum in instrumental conditioning. Science, 304, 452–454.

Ochsner, K.N, Bunge, S.A., Gross, J.J., Gabrieli, J.D.E. (2002). Rethinking feelings: an fMRI study of the cognitive regulation of emotion. Journal of Cognitive Neuroscience, 14, 1215-1229.

Ochsner, K N, Ray, R. D., Cooper, J. C., Robertson, E. R., Chopra, S., Gabrieli, J.D.E., Gross, J.J. (2004). For better or for worse: neural systems supporting the cognitive down- and up-regulation of negative emotion. NeuroImage, 23, 483-499.

Ochsner, K.N., Gross, J.J. (2005). The cognitive control of emotion. Trends in Cognitive Sciences, 9, 242–249.

Ogawa, S., Lee, T.M. (1990). Magnetic resonance imaging of blood vessels at high fields: in vivo and in vitro measurements and image simulation. Magnetic Resonance in Medicine, 16, 9–18.

Ohayon, M. M., Morselli, P. L., Guilleminault, C. (1997). Prevalence of nightmares and their relationship to psychopathology and daytime functioning in insomnia subjects. Sleep, 20, 340–348.

Ohira, H., Nomura, M., Ichikawa, N., Isowa, T., Iidaka, T., Sato, A., Fukuyama, S., Nakajima, T., Yamada, J. (2006). Association of neural and physiological responses during voluntary emotion suppression. NeuroImage, 29, 721-733.

Olatunji, B.O., Williams, N.L., Tolin, D.F., Abramowitz, J.S., Sawchuk, C.N., Lohr, J.M., Elwood, L.S. (2007). The Disgust Scale: item analysis, factor structure, and suggestions for refinement. Psychological Assessment, 19, 281-297.

Oldfield, R.C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia, 9, 97–113.

Paret, C., Brenninkmeyer, J., Meyer, B., Yuen, K.S.L., Gartmann, N., Mechias, M.-L., Kalisch, R. (2011). A test for the Implementation–Maintenance Model of reappraisal. Frontiers in Psychology, 2, 13.

Parks–Stamm, E.J., Gollwitzer, P.M., Oettingen, G. (2007). Action Control by Implementation Intentions: Effective Cue Detection and Efficient Response Initiation. Social Cognition, 25, 248–266.

Parrott, W.G. (1993). Beyond hedonism: motives for inhibiting good moods and for maintaining bad moods. In D.M. Wegner, J.W. Pennebaker (Eds.), Handbook of mental control (pp. 278-308). Englewood Cliffs, N J: Prentice-Hall.

Pascual-Leone, A., Walsh, V., Rothwell, J. (2000). Transcranial magnetic stimulation in cognitive neuroscience--virtual lesion, chronometry, and functional connectivity. Current Opinion in Neurobiology, 10, 232–237.

Payer, D.E., Baicy, K., Lieberman, M.D., & London, E D. (2012). Overlapping neural substrates between intentional and incidental down-regulation of negative emotions. Emotion, 12, 229–235.

Peña-Gómez, C., Vidal-Piñeiro, D., Clemente, I. C., Pascual-Leone, A., Bartrés-Faz, D. (2011). Down-regulation of negative emotional processing by transcranial direct current stimulation: effects of personality characteristics. PLoS ONE, 6(7), e22812

Phan, K.L., Wager, T., Taylor, S.F., Liberzon, I. (2002). Functional neuroanatomy of emotion: a meta-analysis of emotion activation studies in PET and fMRI. Neuroimage, 16, 331–348.

Phan, K.L, Fitzgerald, D.A., Nathan, P.J., Moore, G.J., Uhde, T.W., Tancer, M.E. (2005). Neural substrates for voluntary suppression of negative affect: a functional magnetic resonance imaging study. Biological Psychiatry, 57, 210-219.

Phillips, M.L, Ladouceur, C.D., Drevets, W.C. (2008). A neural model of voluntary and automatic emotion regulation: implications for understanding the pathophysiology and neurodevelopment of bipolar disorder. Molecular Psychiatry, 13, 833-857.

Powell, L. J., Macrae, C.N., Cloutier, J., Metcalfe, J., Mitchell, J.P. (2010). Dissociable neural substrates for agentic versus conceptual representations of self. Journal of Cognitive Neuroscience, 22, 2186-2197.

Premack, D., Woodruff, G. (1978). Does the chimpanzee have a Theory of Mind? Behavioral and Brain Sciences, 1, 515–526.

Preston, S.D., De Waal, F.B.M. (2002). Empathy: Its ultimate and proximate bases. Behavioral and Brain Sciences, 25, 1–20.

Priori, A. (2003). Brain polarization in humans: a reappraisal of an old tool for prolonged non-invasive modulation of brain excitability. Clinical Neurophysiology, 114, 589–595.

Prohovnik, I., Skudlarski, P., Fulbright, R.K., Gore, J.C., Wexler, B.E. (2004). Functional MRI changes before and after onset of reported emotions. Psychiatry Research, 132, 239-250.

Pu, J., Schmeichel, B.J., Demaree, H.A. (2009). Cardiac vagal control predicts spontaneous regulation of negative emotional expression and subsequent cognitive performance. Biological Psychology, 82, 186–195.

Raposo, A., Vicens, L., Clithero, J.A., Dobbins, I.G., Huettel, S.A. (2011). Contributions of frontopolar cortex to judgments about self, others and relations. Social Cognitive and Affective Neuroscience, 6, 260–269.

Redcay, E., Dodell-Feder, D., Pearrow, M.J., Mavros, P.L., Kleiner, M., Gabrieli, J.D.E., Saxe, R. (2010). Live face-to-face interaction during fMRI: a new tool for social cognitive neuroscience. NeuroImage, 50, 1639–1647.

Rohrmann, S., Hopp, H., (2008). Cardiovascular indicators of disgust. International Journal of Psychophysiology, 68, 201–208.

Rottenberg, J., Ray, R. D., Gross, J. J. (2007). Emotion elicitation using films. In J. A. Coan, J. J. B. Allen (Eds.), The handbook of emotion elicitation and assessment. London: Oxford , University Press.

Rowe, J.B., Toni, I., Josephs, O., Frackowiak, R.S., Passingham, R.E. (2000). The prefrontal cortex: response selection or maintenance within working memory? Science, 288, 1656–1660.

Rubia, K. (2009). The neurobiology of meditation and its clinical effectiveness in psychiatric disorders. Biological Psychology, 82, 1-11.

Ruby, P., Decety, J. (2004). How Would You Feel versus How Do You Think She Would Feel? A Neuroimaging Study of Perspective-Taking with Social Emotions. Journal of Cognitive Neuroscience, 16, 988–999.

Ruohonen, J., Karhu, J. (2012). tDCS possibly stimulates glial cells. Clinical Neurophysiology 123, 2006–2009.

Sadleir, R.J., Vannorsdall, T.D., Schretlen, D.J., Gordon, B. (2010). Transcranial direct current stimulation (tDCS) in a realistic head model. NeuroImage, 51, 1310–1318.

Samson, D., Apperly, I.A., Chiavarino, C., Humphreys, G.W. (2004). Left temporoparietal junction is necessary for representing someone else’s belief. Nature Neuroscience, 7, 499-500.

Schaefer, S.M., Jackson, D.C., Davidson, R.J., Aguirre, G.K., Kimberg, D.Y., Thompson-Schill, S.L. (2002). Modulation of amygdalar activity by the conscious regulation of negative emotion. Journal of Cognitive Neuroscience, 14, 913-921.

Schweiger Gallo, I., Keil, A., McCulloch, K.C., Rockstroh, B., Gollwitzer, P.M. (2009). Strategic automation of emotion regulation. Journal of Personality and Social Psychology, 96, 11-31.

Sehm, B., Schäfer, A., Kipping, J., Margulies, D., Conde, V., Taubert, M., Villringer, A., Ragert, P. (2012). Dynamic modulation of intrinsic functional connectivity by transcranial direct current stimulation. Journal of Neurophysiology, 108, 3253–3263.

Seger, C.A., Stone, M., Keenan, J.P. (2004). Cortical Activations during judgments about the self and another person. Neuropsychologia, 42, 1168-1177.

Seidel, E.M., Eickhoff, S.B., Kellermann, T., Schneider, F., Gur, R.C., Habel, U., Derntl, B. (2010). Who is to blame? Neural correlates of causal attribution in social situations. Social Neuroscience, 5, 335-350.

Sheppes, G., Catran, E., Meiran, N. (2009). Reappraisal (but not distraction) is going to make you sweat: physiological evidence for self-control effort. International Journal of Psychophysiology, 71, 91-96.

Sommer, I.E., Aleman, A., Slotema, C.M., Schutter, D.J.L.G. (2012). Transcranial stimulation for psychosis: the relationship between effect size and published findings. The American Journal of Psychiatry, 169, 1211.

Spence, S.A., Kaylor-Hughes, C., Farrow, T.F.D., Wilkinson, I.D. (2008). Speaking of secrets and lies: the contribution of ventrolateral prefrontal cortex to vocal deception. NeuroImage, 40, 1411–1418.

Stagg, C.J., Best, J.G., Stephenson, M.C., O’Shea, J., Wylezinska, M., Kincses, Z.T., Morris, P.G., Matthews, P.M., Johansen-Berg, H. (2009). Polarity-sensitive modulation of cortical neurotransmitters by transcranial stimulation. Journal of Neuroscience, 29, 5202–5206.

Staub, E., Vollhardt, J. (2008). Altruism born of suffering: the roots of caring and helping after victimization and other trauma. The American Journal of Orthopsychiatry, 78, 267–280.

Symmonds, M., Bossaerts, P., Dolan, R.J., (2010). A behavioral and neural evaluation of prospective decision-making under risk. The Journal of Neuroscience, 30, 14380–14389.

Tabibnia, G., Monterosso, J. R., Baicy, K., Aron, A. R., Poldrack, R. A., Chakrapani, S., Lee, B., & London, E. D. (2011). Different forms of self-control share a neurocognitive substrate. The Journal of Neuroscience, 31, 4805–4810.

Tamir, M. (2009). Differential preferences for happiness: extraversion and trait-consistent emotion regulation. Journal of Personality, 77, 447-470.

Thompson-Schill, S.L., Ramscar, M., Chrysikou, E.G. (2009). Cognition without control: when a little frontal lobe goes a long way. Current Directions in Psychological Science, 18, 259-263.

Todorov, A., Engell, A.D. (2008). The role of the amygdala in implicit evaluation of emotionally neutral faces. Social Cognitive and Affective Neuroscience, 3, 303–312.

Torta, D. M., & Cauda, F. (2011). Different functions in the cingulate cortex, a meta-analytic connectivity modeling study. NeuroImage, 56, 2157–2172.

Totterdell, P., Kellet, S., Teuchmann, K., Briner, R.B. (1998). Evidence of mood linkage in work groups. Journal of Personality and Social Psychology, 74, 1504-1515.

Trivers, R. L. (2011). Folly of Fools: The logic of deceit and self-deception in human life. New York, NY: Basic Books

Trosper, S.E., Buzzella, B.A., Bennett, S.M., Ehrenreich, J.T. (2009). Emotion regulation in youth with emotional disorders: implications for a unified treatment approach. Clinical Child and Family Psychology Review, 12, 234-254.

Urry, H.L., van Reekum, C.M., Johnstone, T., Kalin, N.H., Thurow, M.E., Schaefer, H.S., Jackson, C.A., Frye. C.J., Greischer, L.L., Alexander, A.L., Davidson, R.J. (2006). Amygdala and ventromedial prefrontal cortex are inversely coupled during regulation of negative affect and predict the diurnal pattern of cortisol secretion among older adults. The Journal of Neuroscience, 26, 4415-4425.

Van Der Meer, L., Wout, M.V., Aleman, A. (2009). Emotion regulation strategies in patients with schizophrenia. Psychiatry Research, 170, 108-113.

Van Overveld, W.J.M., De Jong, P.J., Peters, M.L. (2009). Digestive and cardiovascular responses to core and animal-reminder disgust. Biological Psychology, 80, 149–157.

Van Overwalle, F., Baetens, K. (2009). Understanding others’ actions and goals by mirror and mentalizing systems: A meta-analysis. NeuroImage, 48, 564-584.

van Reekum, C.M., Johnstone, T., Urry, H.L., Thurow, M.E., Schaefer, H.S., Alexander, A.L., Davidson, R.J. (2007). Gaze fixations predict brain activation during the voluntary regulation of picture-induced negative affect. NeuroImage, 36, 1041–1055.

Van Reekum, C.M., Schaefer, S.M., Lapate, R.C., Norris, C.J., Greischar, L.L., Davidson, R.J., (2011). Aging is associated with positive responding to neutral information but reduced recovery from negative information. Social Cognitive and Affective Neuroscience, 6, 177–185.

Versace, A., Thompson, W.K., Zhou, D., Almeida, J.R.C., Hassel, S., Klein, C.R., Kupfer, D.J., Phillips, M.L. (2010). Abnormal left and right amygdala-orbitofrontal cortical functional connectivity to emotional faces: state versus trait vulnerability markers of depression in bipolar disorder. Biological Psychiatry, 67, 422–431.

Vogeley, K., Bussfeld, P., Newen, A, Herrmann, S., Happé, F., Falkai, P., Maier, W., Shah, N.J., Fink, G.R., Zilles, K. (2001). Mind reading: neural mechanisms of theory of mind and self-perspective. NeuroImage, 14, 170-181.

Vogt, B. A., Finch, D. M., & Olson, C. R. (1992). Functional heterogeneity in cingulate cortex: the anterior executive and posterior evaluative regions. Cerebral Cortex, 2, 435–443.

Volokhov, R.N., Demaree, H.A. (2010). Spontaneous emotion regulation to positive and negative stimuli. Brain and Cognition, 73, 1-6.

Wager, T. D., Davidson, M.L., Hughes, B.L., Lindquist, M.A., Ochsner, K.N. (2008). Prefrontal-subcortical pathways mediating successful emotion regulation. Neuron, 59, 1037-1050.

Wagner, T., Fregni, F., Fecteau, S., Grodzinsky, A., Zahn, M., Pascual-Leone, A. (2007). Transcranial direct current stimulation: a computer-based human model study. NeuroImage, 35, 1113–1124.

Wassermann, E.M. (1998). Risk and safety of repetitive transcranial magnetic stimulation: report and suggested guidelines from the International Workshop on the Safety of Repetitive Transcranial Magnetic Stimulation, June 5-7, 1996. Electroencephalography and Clinical Neurophysiology, 108, 1–16.

Watson, D., Clark, L. (1994). The PANAS-X: Manual for the positive and negative affect schedule-Expanded Form. Iowa: University of Iowa.

Webb, T.L., Miles, E., Sheeran, P. (2012). Dealing with feeling: A meta-analysis of the effectiveness of strategies derived from the process model of emotion regulation. Psychological Bulletin, 138, 775–808.

Webb, T.L., Sheeran, P. (2003). Can implementation intentions help to overcome ego-depletion? Journal of Experimental Social Psychology, 39, 279–286.

Webb, T. L., Sheeran, P. (2007). How do implementation intentions promote goal attainment? A test of component processes. Journal of Experimental Social Psychology, 43, 295-302.

Webb, T.L., Sheeran, P., Totterdell, P., Miles, E., Mansell, W., Baker, S. (2012). Using implementation intentions to overcome the effect of mood on risky behaviour. The British Journal of Social Psychology, 51, 330–345.

Webb, T.L., Schweiger Gallo, I., Miles, E., Gollwitzer, P.M., Sheeran, P. (2012). Effective regulation of affect: An action control perspective on emotion regulation. European Review of Social Psychology, 23, 143–186.

Werner, K., Gross, J.J. (2010). Emotion regulation and psychopathology: A conceptual framework. In A. Kring, D. Sloan (Eds.), Emotion regulation and psychopathology. (pp. 13-37) Guilford Press: New York

Whitwell, J.L. (2009). Voxel-based morphometry: an automated technique for assessing structural changes in the brain. The Journal of Neuroscience, 29, 9661–9664.

Williams, L.M., Brammer, M.J., Skerrett, D., Lagopolous, J., Rennie, C., Kozek, K., Olivieri, G., Peduto, T., Gordon, E. (2000). The neural correlates of orienting: an integration of fMRI and skin conductance orienting. NeuroReport, 11, 3011–3015.

Winecoff, A., Labar, K.S., Madden, D.J., Cabeza, R., Huettel, S.A. (2011). Cognitive and neural contributors to emotion regulation in aging. Social Cognitive and Affective Neuroscience, 6, 165–176.

Wirth, M., Rahman, R.A., Kuenecke, J., Koenig, T., Horn, H., Sommer, W., Dierks, T. (2011). Effects of transcranial direct current stimulation (tDCS) on behaviour and electrophysiology of language production. Neuropsychologia, 49, 3989–3998.

Young, L., Dodell-Feder, D., Saxe, R. (2010). What gets the attention of the temporo-parietal junction? An fMRI investigation of attention and theory of mind. Neuropsychologia, 48, 2658-2664.

Yuan, J., Luo, Y., Yan, J.H., Meng, X., Yu, F., Li, H. (2009). Neural correlates of the females’ susceptibility to negative emotions: An insight into gender-related prevalence of affective disturbances. Human Brain Mapping, 30, 3676-3686.

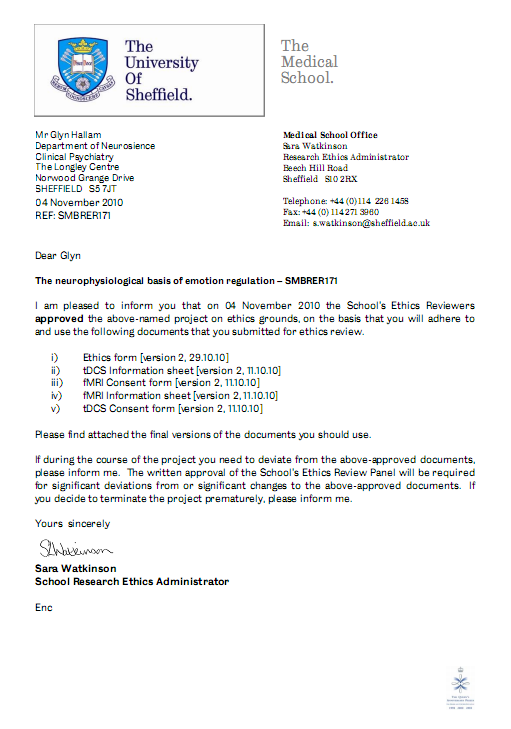
Zhang, W., Li, F., Qin, S., Luo, J. (2012). The integrative effects of cognitive reappraisal on negative affect: associated changes in secretory immunoglobulin A, unpleasantness and emotion regulation activity. PLoS ONE, 7, e30761.

Zheng, X., Alsop, D. C., Schlaug, G. (2011). Effects of transcranial direct current stimulation (tDCS) on human regional cerebral blood flow. NeuroImage, 58, 26–33

Ziegler, G., Dahnke, R., Jäncke, L., Yotter, R.A., May, A., Gaser, C. (2012). Brain structural trajectories over the adult lifespan. Human Brain Mapping, 33, 2377–89.

# Appendices

## Appendix 1 – Ethical approval for the studies



## Appendix 2 – Consent form for fMRI studies

**RESEARCH CONSENT FORM**

**‘**The Neurophysiological Basis of Emotion Regulation**’**

Please initial:

I have read and understood the Volunteer Information Sheet ......................

I have had an opportunity to ask questions and discuss this study......................

I have received satisfactory answers to my questions ......................

I have received enough information about the study ......................

Please tick the following two boxes if you agree with the statements:-

1. In the unlikely event of any brain abnormality being detected on the MRI scan my GP will be informed.
2. I also confirm that I have not answered “yes” to any of the following questions.
3. Do you have a pacemaker or artificial heart valve?
4. Have you had any brain operations e.g. insertion of aneurysm clips or metal plates?
5. Have you had any recent surgery to your head or body (within the last two months)?
6. Do you have any joint replacements or metal implants e.g. screws?
7. Have you EVER had metal in your eyes e.g. from a lathe in a machine shop?
8. Do you have any shrapnel from a war injury or previous gunshot injury?
9. Do you wear a false limb, calliper or brace?
10. Do you wear dentures, or a dental plate?
11. Have you ever suffered from epilepsy or blackouts?
12. Do you have any ear implants e.g. cochlear?
13. Do you have any non-removable rings attached to your body?
14. Is there any chance that you might be pregnant?

To whom have you spoken? ...........................................................................

Do you understand that you do not need to take part and if you do enter you are free to withdraw at any time, without having to give a reason? **YES / NO**

Do you agree to take part in this study? **YES / NO**

Signed...............................................Name(BLOCKLETTERS)....................................................

Date................

(Participant to complete)

I confirm that I have fully explained the purpose and nature of the study and the risks involved.

Signed:...............................................Name(BLOCKLETTERS)....................................................

Date................

(Researcher to complete)

## Appendix 3 – tDCS consent form

**RESEARCH CONSENT FORM**

‘Modulation of emotion regulation ability by transcranial direct current stimulation (tDCS)’

Please initial:

I have read and understood the Volunteer Information Sheet ....................

I have had an opportunity to ask questions and discuss this study....................

I have received satisfactory answers to all my questions ...................

I confirm that I have no history of epilepsy/seizures or ...................

other neurological problems

I have received enough information about the study ..................

To whom have you spoken ...........................................................................

I understand that I do not need to take part and if I do enter

I am free to withdraw at any time, without having to give a reason ....................

I agree to take part in this study ....................

Signed:...............................................Name(BLOCKLETTERS)....................................................

Date................

(Participant to complete)

I confirm that I have fully explained the purpose and nature of the study and the risks involved.

Signed:...............................................Name(BLOCKLETTERS)....................................................

Date................

(Researcher to complete)

## Appendix 4 – Description of video clips used in chapter 2

|  |  |  |  |
| --- | --- | --- | --- |
| Clip Name | Description | Target emotion | Source |
| **Child war victims**  **Eating dog muck**  **Filthy toilet**  **Dead Baby**  **Dead children**  **Infected spot**  **Hairwash**  **Rugby**  **Visiting doctor**  **Arm amputation**  Dying seal | Broadcast news footage showing a man crying over the bodies of his three children who were innocent war victims. The bodies have some dried blood around the faces, but are otherwise covered by an opaque sheet.  Taken from the film “Pink Flamingos”, clips shows a woman sitting down and scooping up with her hand some dog faeces, which she then eats.  Taken from the film “Trainspotting”, a man kneels over a filthy toilet and places his hand in the bowl, as if searching for something, whilst visibly gagging.  Taken from the film “Trainspotting”, the camera pans around a cot in which the body of a baby lies. The body shows no sign of external injury but is implied to have died of sudden infant death syndrome (SIDS).  Broadcast news footage showing the bodies of children lying on trays in a morgue. The bodies do not show signs of external distress, and are mostly covered by opaque sheets, though the heads can be seen.  Close-up of someone squeezing their spot. The spot eventually breaches and a small amount of white puss emerges.  Woman having her hair washed in a salon  Benign passage of play from a professional game of rugby  Doctor reading a man’s blood pressure using a sphygmomanometer  Footage from a medical instruction video showing an arm amputation  Footage showing a bleeding seal that has been clubbed | Sadness  Disgust  Disgust  Sadness  Sadness  Disgust  Neutral  Neutral  Neutral  Disgust  D**isgu**st | News footage from “Al Jazeera”  http://www.youtube.com/watch?v=K5wrwZlwAq  8&feature=related  1972 film “Pink Flamingos”  1996 film “Trainspotting”  1996 film “Trainspotting”  AFP news  http://www.youtube.com/watch?v=PsFEdv4y5tY  &feature=related  Home video on Youtube  http://www.youtube.com/watch?v=DkwUEOOa7yg  TV programme  http://www.youtube.com/watch?v=LyoUa9rHmVQ  TV coverage of match  http://www.youtube.com/watch?v=qC6kxqbPwfY  Medical instruction video  http://www.youtube.com/watch?v=0L3hV-PLlC4  Medical instruction video  Charity promotional video  http://www.youtube.com/watch?v=zwg0Sftx1e |

## Appendix 5 – IAPS images used in chapter 3

IAPS Disgust:

2352.2, 2981, 3010, 3015, 3016, 3051, 3053, 3060, 3061, 3062, 3063, 3064, 3068, 3069, 3071, 3080, 3100, 3101, 3102, 3120, 3140, 3150, 3168, 3170, 3266, 3400, 7360, 8230, 9180, 9253, 9300, 9301, 9320, 9405, 9433, 9570

IAPS Sad:

2053, 2095, 2205, 2276, 2278, 2375.1, 2490, 2590, 2688, 2703, 2710, 2750, 2799, 2900, 3216, 3220, 3230, 3301, 3302, 3350, 6022, 6838, 7053, 9000, 9041, 9050, 9180, 9182, 9250, 9290, 9410, 9421, 9435, 9520, 9910, 9921

IAPS Neutral:

2580, 2850, 5390, 5720, 7009, 7010, 7025, 7031, 7040, 7052, 7080, 7090, 7150, 7235, 9008

## Appendix 6 – Disgust Sensitivty Scale revised

**Please indicate how much you agree with each of the following statements, or how true it is about you. Please write a number (0-4) to indicate your answer:**

**0** = Strongly disagree (very untrue about me)

**1** = Mildly disagree (somewhat untrue about me)

**2** = Neither agree nor disagree

**3** = Mildly agree (somewhat true about me)

**4** = Strongly agree (very true about me)

\_\_\_\_1. I might be willing to try eating monkey meat, under some circumstances.

\_\_\_\_2. It would bother me to be in a science class, and to see a human hand preserved in a jar.

\_\_\_\_3. It bothers me to hear someone clear a throat full of mucous.

\_\_\_\_4. I never let any part of my body touch the toilet seat in public restrooms.

\_\_\_\_5. I would go out of my way to avoid walking through a graveyard.

\_\_\_\_6. Seeing a cockroach in someone else's house doesn't bother me.

\_\_\_\_7. It would bother me tremendously to touch a dead body.

\_\_\_\_8. If I see someone vomit, it makes me sick to my stomach.

\_\_\_\_9. I probably would not go to my favorite restaurant if I found out that the cook had a cold.

\_\_\_\_10. It would not upset me at all to watch a person with a glass eye take the eye

out of the socket.

\_\_\_\_11. It would bother me to see a rat run across my path in a park.

\_\_\_\_12. I would rather eat a piece of fruit than a piece of paper

\_\_\_\_13. Even if I was hungry, I would not drink a bowl of my favorite soup if it had been

stirred by a used but thoroughly washed flyswatter.

\_\_\_\_14. It would bother me to sleep in a nice hotel room if I knew that a man had died of a heart attack in that room the night before.

**How disgusting would you find each of the following experiences? Please write a**

**number (0-4) to indicate your answer:**

**0** = Not disgusting at all

**1** = Slightly disgusting

**2** = Moderately disgusting

**3** = Very disgusting

**4** = Extremely disgusting

\_\_\_\_15. You see maggots on a piece of meat in an outdoor garbage pail.

\_\_\_\_16. You see a person eating an apple with a knife and fork

\_\_\_\_17. While you are walking through a tunnel under a railroad track, you smell urine.

\_\_\_\_18. You take a sip of soda, and then realize that you drank from the glass that an

acquaintance of yours had been drinking from.

\_\_\_\_19. Your friend's pet cat dies, and you have to pick up the dead body with your bare hands.

\_\_\_\_20. You see someone put ketchup on vanilla ice cream, and eat it.

\_\_\_\_21. You see a man with his intestines exposed after an accident.

\_\_\_\_22. You discover that a friend of yours changes underwear only once a week.

\_\_\_\_23. A friend offers you a piece of chocolate shaped like dog‑doo.

\_\_\_\_24. You accidentally touch the ashes of a person who has been cremated.

\_\_\_\_25. You are about to drink a glass of milk when you smell that it is spoiled.

\_\_\_\_26. As part of a sex education class, you are required to inflate a new unlubricated

condom, using your mouth.

\_\_\_\_27. You are walking barefoot on concrete, and you step on an earthworm.

## Appendix 7 – PANAS-X

This scale consists of a number of words and phrases that describe different feelings and emotions. Read each item and then mark the appropriate answer in the space next to that

word. Indicate to what extent you feel this way *right now*. Use the following scale to

record your answers:

**1** **2** **3** **4** **5**

very slightly a little moderately quite a bit extremely

or not at all

1. \_\_\_\_\_\_ cheerful

2. \_\_\_\_\_\_ disgusted

3. \_\_\_\_\_\_ attentive

4. \_\_\_\_\_\_ bashful

5. \_\_\_\_\_\_ sluggish

6. \_\_\_\_\_\_ daring

7. \_\_\_\_\_\_ surprised

8. \_\_\_\_\_\_ strong

9. \_\_\_\_\_\_ scornful

10. \_\_\_\_\_\_ relaxed

11. \_\_\_\_\_\_ irritable

12. \_\_\_\_\_\_ delighted

13. \_\_\_\_\_\_ inspired

14. \_\_\_\_\_\_ fearless

15. \_\_\_\_\_\_ disgusted with self

16. \_\_\_\_\_\_ sad

17. \_\_\_\_\_\_ calm

18. \_\_\_\_\_\_ afraid

19. \_\_\_\_\_\_ tired

20. \_\_\_\_\_\_ amazed

21. \_\_\_\_\_\_ shaky

22. \_\_\_\_\_\_ happy

23. \_\_\_\_\_\_ timid

24. \_\_\_\_\_\_ alone

25. \_\_\_\_\_\_ alert

26. \_\_\_\_\_\_ upset

27. \_\_\_\_\_\_ angry

28. \_\_\_\_\_\_ bold

29. \_\_\_\_\_\_ blue

30. \_\_\_\_\_\_ shy

31. \_\_\_\_\_\_active

32. \_\_\_\_\_\_guilty

33. \_\_\_\_\_\_ joyful

34.\_\_\_\_\_\_\_nerous

35.\_\_\_\_\_\_lonely

36\_\_\_\_\_\_\_sleepy

37\_\_\_\_\_\_ excited

38.\_\_\_\_\_\_ hostile

39.\_\_\_\_\_\_ proud

40.\_\_\_\_\_ jittery

41.\_\_\_\_\_\_ lively

42.\_\_\_\_\_\_ ashamed

43. \_\_\_\_\_\_ at ease

44.\_\_\_\_\_\_ scared

45.\_\_\_\_\_ drowsy

46. \_\_\_\_\_\_ angry at self

47.\_\_\_\_\_\_ enthusiastic

48. \_\_\_\_\_\_ downhearted

49. \_\_\_\_\_\_ sheepish

50. \_\_\_\_\_\_ distressed

51. \_\_\_\_blameworthy

52. \_\_\_\_\_\_ determined

53. \_\_\_\_\_\_ frightened

54. \_\_\_\_\_\_ astonished

55. \_\_\_\_\_\_ interested

56. \_\_\_\_\_\_ loathing

57. \_\_\_\_\_\_ confident

58. \_\_\_\_\_\_ energetic

59. \_\_\_\_\_\_ concentrating

60. \_\_\_\_\_\_ dissatisfied with self

**Scales**

General Positive Emotion:= (p31 + p25 + p3 + p52 + p47 + p37 + p13 + p55 + p39 + p8)

General Negative Emotion:= (p18 + p44 + p34 + p40 + p11 + p38 + p32 + p42 + p26 + p50)

fear:= (p18 + p44 + p53 + p34 + p40 + p21)

hostility:= (p37 + p38 + p11 + p9 + p2 + p56)

guilt:= (p32 + p42 + p51 + p46 + p15 + p60)

sadness:= (p16 + p29 + p48 + p24 + p35)

joviality:= (p22 + p33 + p12 + p1 + p37 + p47 + p41 + p58)

self\_assurance:= (p39 + p3 + p57 + p28 + p6 + p14)

attentiveness:= (p25 + p3 + p59 + p52)

shyness:= (p30 + p4 + p49 + p23)

fatigue:= (p36 + p19 + p5 + p45)

serenity:= (p17 + p10 + p43)

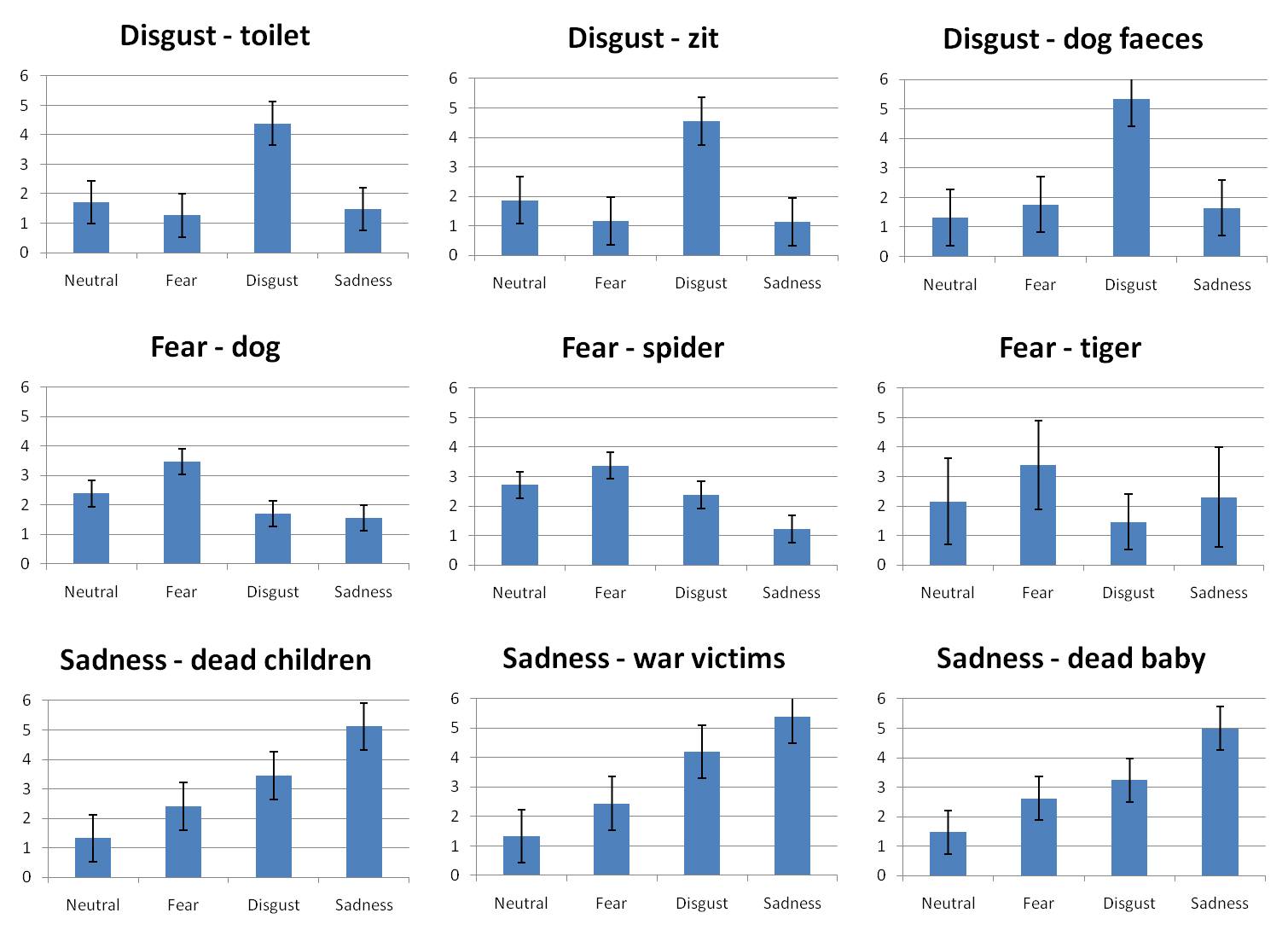
surprise:= (p20 + p7 + p54)

basicpositive affect:= (joviality+self\_assurance+attentiveness)/3

basic negative affect:= (sadness+guilt+hostility+fear)/4

## Appendix 8

Mean ratings (N = 34) and standard errors for each of four emotional dimensions (neutral; fear; disgust; sadness) for videos selected from the initial piloting.

****