

Effects of Yoga Experience Compared to Exercise on Functional Connectivity in  
Distributed Brain Networks

by

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## **Abstract**

**Introduction:** During a difficult life event, such as dealing with a chronic health condition, practicing acceptance of the difficulty alters the context in which a person views that difficulty. Acceptance of that difficulty reduces negative avoidant emotions that are key aspects of anxiety and depression. Acceptance is a central training feature of many contemplative practices, such as yoga. However, we lack a complete understanding of the underlying mechanisms that successfully train acceptance, and methods for validating their successful transfer ‘off the matt’ in order to benefit the general public in their everyday lives.

**Method:** During rest, functional magnetic imaging was used in yoga practitioners (YP) and recreational athletes (RA) to determine how practice of these activities induces lasting functional connectivity changes. In a previous study, the right Supramarginal gyrus (rSMG) was shown to be active during emotionally eliciting video clips in YP when compared to RA (Wadden et al., 2015). We examined both whole brain resting state, independent component analysis (ICA) of the rSMG as a region of interest (ROI), and cortical thickness.

**Results:** Whole brain resting state analysis showed YP group activated clusters of voxels in the L Precuneus and R Superior Frontal Gyrus and RA group activated clusters of voxels in the Left Frontal Pole and R MFG. The rSMG ROI formed a network with YP group activated clusters of voxels in the L Superior

Frontal Gyrus, R Precentral Gyrus, and R Precuneus and RA group activated clusters of voxels in the R Superior Medial Gyrus, R Lingual Gyrus, and L Thalamus.

**Conclusions:** During whole brain resting state and ROI rSMG analysis YP compared to RA showed integration with the Precuneus, a region typically implicated in the default mode network (DMN), and the LDLPFC and the rSMG, both parts of the Frontoparietal network (FPN). This greater integration within and between networks indicates a relationship between individuals who practice habitual attentional training practices and typical anticorrelated systems of attention and the narrative self.

## **Preface**

This thesis and the collection of the data is based off of the industrial partnership with Lululemon Athletica and the Brain and Behavior Lab. The thesis is based on the resting state data set and the structural MRI scans of the subjects from the industrial partnership which has not been examined before, therefore the thesis is original, unpublished, and not taken directly from previously published articles.

The data collection and MRI acquisition was done primarily by Katie Wadden. The construction of the test, preprocessing of the data, whole brain and ROI ICA analysis are my original work.

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## **List of Symbols, Abbreviations or Other**

YP – yoga practitioners

RA – recreational athletes

ICA – independent component analysis

ROI – region of interest

SMG – Supramarginal gyrus

DMN – default mode network

FPN – frontoparietal network

FPAN – frontoparietal attention network

iFPN – integrative frontoparietal network

DLPFC – dorsolateral prefrontal cortex

FEF – frontal-eye-field

IPL – inferior parietal lobule

LIP – lateral interparietal neurons

IPS – inferior parietal sulcus

SLF - superior longitudinal fasciculus

ES – experiential self

NS – narrative self

DAS- dorsal attention system

HCMS - hippocampal-cortical memory system

AIC – anterior insula cortex

dACC – dorsal anterior cingulate cortex

TMS - transcranial magnetic stimulation

MFG – Middle Frontal Gyrus

IFG - Inferior Frontal Gyrus

METs – Metabolic Equivalents of Task

MAAS – Mindful Attention Awareness Scale

PSS – Cohen’s Perceived Stress Scale

DASS – Depression Anxiety Stress Scale

BOLD - blood oxygenation level dependent

LFF – low frequency fluctuations

PCC – posterior cingulate cortex

PCu – precuneus

IPL – Inferior Parietal Lobe

## **Acknowledgements**

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Many thanks to Dr. Farah Shroff for inspiring me through her deep expertise at the intersection of eastern and western philosophy. Farah's strive to bring contemplative practices mainstream for the greater good of society will have impacts for generations to come.

Special thanks to Dr. Lara Boyd who managed to provide exceptionally detailed and rigorous feedback in between her constant stream of grant writing, supervising and other commitments.

## **Chapter One: Introduction**

### **Yoga as a Clinical Intervention: Basic Psychological Framework**

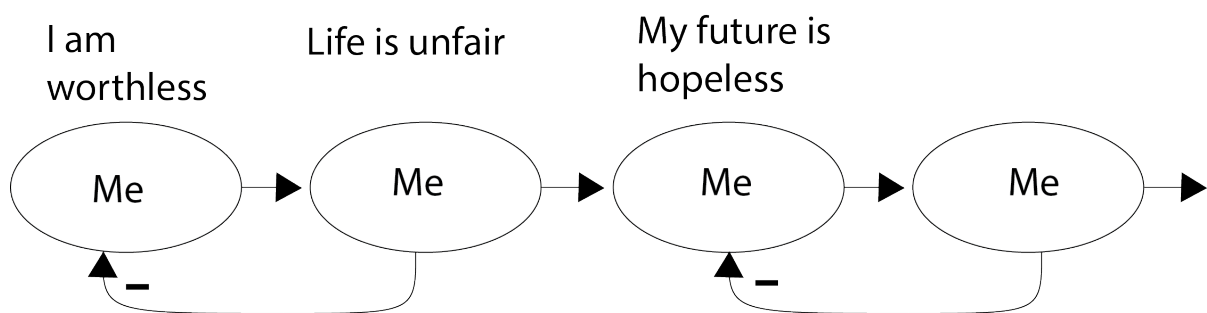
Modern day clinical interventions have secularized eastern Buddhist mindfulness practices with the aim of improving maladaptive behaviors through common pathways for increasing awareness and improving affective response to discursive thoughts, feelings and bodily sensations (Carmody, Baer, Lykins, & Olendzki, 2009). For example, interventions have been created for general stress reduction, depression relapse, substance abuse disorder, broad behavioral health-conditions (Benson & Hartz, 2000; Hayes, Luoma, Bond, Masuda, & Lillis, 2006; Kabat-Zinn, 1990; Linehan, 1993; Segal, Williams, & Teasdale, 2001; Witkiewitz & Bowen, 2010). Similarly, yoga has been adapted to specific clinical programs, and has been shown to improve a wide range psychological problems (Field, 2011). This research will be building on basic and applied research from both contemplative disciplines, due to their similarities. Though yoga differs from mindfulness in lineage, the same principles of non-judgmental awareness to the present moment are reinforced through meditative instruction (Bishop, 2004; Kabat-Zinn, 1990) The shared psychological mechanism of these clinical interventions is the disruption of the reification of a negative self-concept created through past, present and prospective narrative (see Figure 1) (Beck, 1979).

Over time without intervention, negative affective responses to transient mental and environmental events tune the visual-cognitive processing of basic

elements of our reality, influencing how we perceive affectively valenced content in our environment. This form of implicit emotion regulation is referred to as affect-biased attention (Todd, Cunningham, Anderson, & Thompson, 2012). In this research, we will explore this theoretical regulatory mechanism through the comparison of neural activity in yoga practitioners and recreational athletes.

**Figure 1: Reification of Negative Self-Concept Reinforcing Affect Attention**

**Bias**



**Emotion Regulation Strategies: Affect-Biased Attention**

Emotion regulation strategies fall into two distinct categories: antecedent-focused strategies, that act on the input of the emotion-generative process before the emotionally eliciting event, and response-focused strategies, that act on the output of the process after the event (Gross, 1998). Time-based evaluations of emotion regulation strategies may indicate differences in neural recruitment and processing in brain regions detectable by neuroimaging techniques used in the present study. Examples of these two strategies that are commonly used in the down-regulation of emotion are cognitive reappraisal and expressive suppression (Frank et al., 2014). Antecedent-focused cognitive reappraisal involves actively

reinterpreting emotionally eliciting cues in ones' conscious environment, resulting in a new emotional outcome; Expressive suppression is a response-focused process of deliberately limiting emotional behavior once the subject is emotionally aroused (Butler, Wilhelm, & Gross, 2006; Gross, 1998).

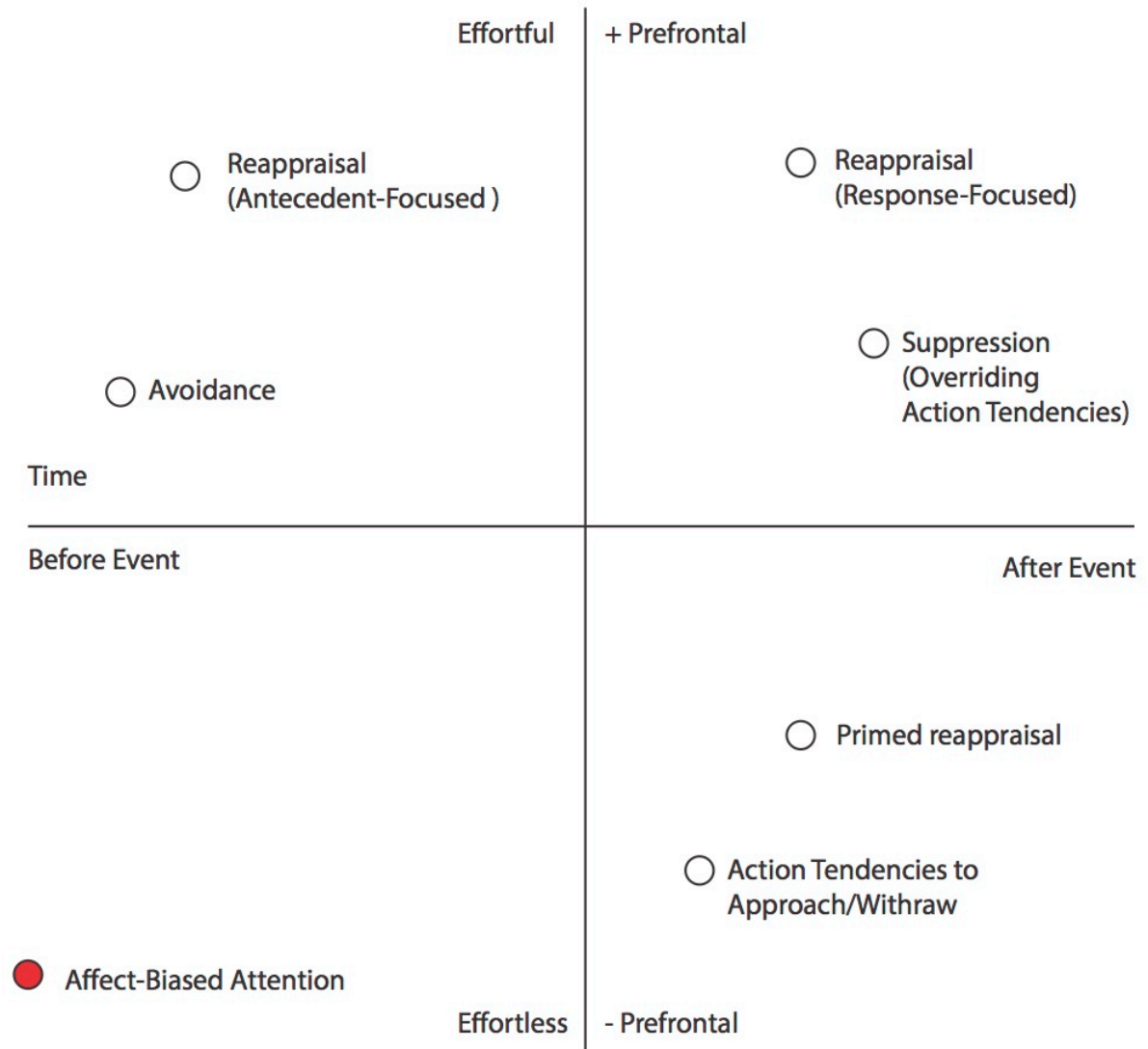
Since emotions are temporal events, distinguishing emotion regulation strategies through a process model allows affective researchers to identify strategies that allow the people to modify their overall affective experience during the emotion generation process (Barrett & Gross, 2001). Reappraisal and suppression have major temporal distinctions, with reappraisal recruiting prefrontal resources earlier in the emotion generation process compared to suppression (Goldin, McRae, Ramel, & Gross, 2008). In addition to time, both down-regulation strategies require a level of cognitive control and therefore these strategies recruit prefrontal resources to decrease negative emotional experience.

Not all emotion regulation strategies provide the same outcomes. Expressive suppression increases activation in the amygdala and insula, areas associated with both the generation of emotions and the subsequent integration of the visceral response to emotion. Due to early PFC activation, reappraisal intervenes within the emotion generation process, decreasing the emotional response, while suppression masks and dampens the emotion after it is generated (Goldin et al., 2008).

Though reappraisal is more adaptive than expressive suppression, both of these effortful emotion regulation strategies differ from an effortless acceptance-based strategy. For example, cognitive reappraisal reinforces, a relationship to

thoughts and emotions as stable aspects of an individual's existence that need to be acted upon, rather than transient mental phenomena that arise and dissipate over time not needing to be altered (Chambers, Gullone, & Allen, 2009). Teaching acceptance through repetitive attentional exercises allows the individual to influence the bottom-up saliency system, which influences what external and internal affective stimuli are being processed also referred to as the affect attention bias (Pessoa & Adolphs, 2010; Todd et al., 2012).

**Figure 2: Emotion Regulation Strategy Matrix: Affect Attention Bias**



Affect-biased attention is measured using a dot-probe task, where response time is measured after a probe is presented in a spatial location before a valence stimulus is presented (Fox, Russo, & Dutton, 2002). Affect-biased attention has been modified using a mindfulness based intervention with fibromyalgia patients in response to pain related words (Vago & Nakamura, 2011). This is important, as the



attentional biases identified on the dot-probe task predicts emotional responsiveness to stressors, indicating that there may be a relationship between the attentional training given to the patients and the affect attention bias (Hertel & Mathews, 2011; MacLeod, Koster, & Fox, 2009).

## **The Frontal Parietal Attentional Network and The Role of The Supramarginal Gyrus**

Dorsal frontal and parietal regions form the Frontal Parietal Attentional Network (FPAN) [Dorsolateral Prefrontal Cortex (DLPFC), Frontal Eye Field (FEF), Inferior Parietal Sulcus (IPS), Inferior Parietal Lobe (IPL), the visual cortex], a network that is crucial to the processing, orienting, selection, and switching of sensory content. It has been proposed that high levels of connectivity within the FPAN are important for contemplative practices (Vago & Silbersweig, 2012). This research explores changes in this network in comparison to a non-contemplative group in order to strengthen current theoretical models of contemplative practices. The SMG is a substructure of the IPL; this network facilitates the integration of bottom-up and top-down inputs. These inputs converge in a reciprocal manner with the lower processed sensory features being elaborated on from higher control systems managing behavioral goals and action templates. The FPAN biases sensory competition favoring perceptual features that align with the highest priority in the control systems (Ptak, 2012). Evidence of the top-down reciprocal information flow can be seen through physiological processes such as confirmation bias, the tendency to map new life events to our world view and disregard information that

would challenge it (Nickerson, 1998). Though affect attention bias follows a similar pattern of reciprocal feedback from top-down attentional resources, the FPAN receives visual information early in the visual cortex processing hierarchy and slightly before the inferior temporal cortex (Bisley, Krishna, & Goldberg, 2004; Bullier, 2001). This early information flow indicates that it is functionally possible for the FPAN to influence affect attention bias very early in the processing of visual information. For example, it is advantageous for the FPAN to influence the reorienting to a suddenly appearing affectively valenced object before the information is visually processed.

### **Shift in Parietal to Frontal Activation Predicts Attentional Bias**

Monkey's Lateral Interparietal (LIP) neurons, which are a part of the IPS, predicted the location of a target in a visual discrimination pop out task before Frontal Eye Fields (FEF) and other prefrontal regions were activated (Buschman & Miller, 2007). In humans the shift in activation between the IPL, a larger structure of the SMG, and the FEF predicted a reflexive saccade 100 ms before onset (Ptak, 2012). The FEF, which are responsible for action templates, appear to be a major driver for influencing affect attention bias in the visual processing stage. These characteristic shifts in parietal and frontal activation within the FPAN predict whether the processing is a reflexive bias or guided by a goal-driven action. These studies show that the FPN bottom-up structures such as the IPS and IPL (SMG), which are responsible for priority maps and switching/orienting of attention, have a major role in reflexive affect attention bias. Examining functional connectivity in parietal

regions, specifically the SMG, between yoga practitioners and recreational athletes will indicate whether contemplative practices may influence these network dynamics.

### **The Anatomy of the FPAN and the Supramarginal Gyrus**

The dorsal and ventral frontoparietal cortex is strongly innervated through the superior longitudinal fasciculus (SLF) (Ptak, 2012). With the SLF-III directly interconnecting the SMG, FEF, the ventrolateral and dorsolateral cortex, which are responsible for basic social cognition and theory of mind (Ptak, 2012). For example the ventral premotor cortex, which is strongly connected between the SMG with SLF-III, was the first area discovered as part of the mirror neuron system, which is where neurons respond to executed movement and similar movements as others (Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). A meta-analysis of morphometric neuroimaging studies for meditation practitioners reported that the SLF as one of two white matter regions with robust convergent brain structure differences in meditation practitioners (Fox et al., 2014). Findings of greater cortical thickness in yoga practitioners compared to recreational athletes may help elucidate underlying differences in functional activity between both groups.

### **The Functional Overlap and Attentional Training Effects between the FPN (Dorsolateral PFC & Supramarginal gyrus), Task-Negative and Task-Positive Networks**

The FPAN outlined has been predominately researched for processing, selecting and influencing the attention of visual sensation and perception of the

external world; however the integrative frontoparietal network (iFPN) has been proposed to go beyond an external visual attention system. The iFPN has also been proposed to self-regulate internally directed thought using long-term memory (Buckner & Carroll, 2007; Vincent, Kahn, Snyder, Raichle, & Buckner, 2008). Distinguishing between differences in FPN networks for regulating internal and external stimuli is important due to the repeated guidance to monitor both external and internal distractors in the contemplative practitioners environment. The iFPN overlaps with other networks and is uniquely situated to integrate information coming from three systems (1) the experiential self (ES) responsible for unaware and aware present moment first person experience, (2) the narrative self (NS) otherwise known as the default mode network (DMN) which is responsible for evaluative thought and mind wandering, and (3) the prosociality system which is responsible for altruistic actions (Vago & Silbersweig, 2012).

The FPN and the iFPN network have functional network differences with the integrative network having the caveat of some functional roles not having a reducible functional area. Instead, the iFPN and the three overlapping networks are contextually dependent; however, many of the same structures that contribute to visual attention contribute to the iFPN's network characteristics, such as the DLPFC and the SMG. The chassis of all four networks are the Task-Positive and Task-Negative networks are the dorsal attention system (DAS) and the hippocampal-cortical memory system (HCMS) (Broyd et al., 2009; Fox et al., 2005; Vincent et al., 2008). Both networks have been previously found to be anti-correlated to each other, with the DAS positively correlated and HCMS anticorrelated to goal-directed

action (Fox et al., 2005; Vincent et al., 2008). These networks have been further parsed and theorized to represent different aware and unaware states of experiential self processing (A. Damasio, 2010; Gallagher, 2000; James, 1892).

### **Functional Coupling of the FPN and the Default Mode Network or Narrative Self**

At the turn of the 21<sup>st</sup> Century, a task-negative network was discovered (Raichle, MacLeod, et al., 2001). The HCMS is a subnetwork of the default-mode network (DMN), which processes the narrative self. The DMN is responsible for psychological processes such as ruminating on the past (Raichle, MacLeod, et al., 2001; Spreng, Mar, & Kim, 2008), predicting the future (Buckner & Carroll, 2007), and making personal, social and moral judgments (Andrews-hanna, Reidler, Huang, & Buckner, 2010; Harrison et al., 2008). The DMN functional and structural connectivity both supports the recruitment of the medial prefrontal cortex (MPFC), medial temporal lobes (MTLs), and posterior cingulate cortex (PCC)/retrosplenial cortex (RSC) as the key structures in narrative self processing (Greicius, Supekar, Menon, & Dougherty, 2009).

Until recently, DMN activity has been thought to be exclusively anti-correlated with the FPN (Fox et al., 2005). It was generally believed that these two networks exclusively compete and do not cooperate. The DMN was seen as being responsible for linking moment to moment experiences to create an internal narrative of the past in order to predict the future and the FPN was primarily an 'earlier' extrinsic network meant to deal with moment to moment external

environmental tasks in our day to day lives (Josipovic, Dinstein, Weber, & Heeger, 2011). The underlying logic is based on one not being able to be in the moment while linking past moments into a cohesive narrative. However, using sophisticated resting state analysis, researchers have identified network coupling between the FPN and DMN during mind wandering, especially when the subject was not aware they were mind wandering (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Schooler et al., 2011; Smallwood, Brown, Baird, & Schooler, 2012). Similarly, researchers have made a distinction between the aware and unaware experiential self (A. R. Damasio, 1999; Gallagher, 2000; James, 1892; Legrand, 2007; Northoff & Panksepp, 2008).

### **Attentional Training Increases Functional Connectivity Between Networks**

Contemplative practices have been shown to change the functional connectivity of the DMN and other overlapping networks. Experienced meditators have increased connectivity between the FPN, specifically parts of the PFC, and the right inferior parietal lobule, which includes the R SMG (Carhart-Harris et al., 2013; V. a. Taylor et al., 2013). Importantly, a lack of integration of the FPN and the NS may contribute significantly to issues of emotional regulation (Bressler & Menon, 2010) and affective biased attention (Todd et al., 2012). Bottom-up switching between Task-Positive and Task-Negative networks has generally been attributed to the functional and structural anterior insular cortex (AIC) and the dorsal anterior cingulate cortex (dACC) (Bressler & Menon, 2010). Attentional training techniques that generate awareness have been widely attributed to the activation of the DLPFC,

the ACC, and the insula (Chiesa & Serretti, 2011; Holzel et al., 2011; Lutz, Dunne, & Davidson, 2007; Rubia, 2009). Therefore, these networks have been hypothesized as the main regulatory mechanism for influencing affect attention bias and other forms of emotion regulation (Grant, Courtemanche, Duerden, Duncan, & Rainville, 2010; Hölzel et al., 2008, 2011; Lazar et al., 2005; Luders, Toga, Lepore, & Gaser, 2009; Manna et al., 2010; Pagnoni, Cekic, & Guo, 2008). However, little research has explored how the SMG, an area responsible for reorienting and switching attentional resources, may be involved in the switching between task-positive, task-negative and prosocial networks.

### **Insight (Vipassana) An Acceptance-Based Practice for Influencing Affect Attention Bias**

Insight is characterized by a sudden and intuitive shift in perspective (Gabora & Ranjan, 2013; Schooler, Ohlsson, & Brooks, 1993). Insight is an elusive psychological process, because it is produced in an unaware state; however, attentional training techniques may influence attentional biases leading to shifts in perspective and insight. For example, one such attentional training technique Vipassana as taught from the SN Goenka tradition, which translates as insight meditation, emphasizes acceptance of the present moment during a habitual attentional focus and switching body scan practice. Effortless switching of social and affective cognition, a product of insight, can be experimentally induced by transcranial magnetic stimulation (TMS) of the rSMG (Silani, Lamm, Ruff, & Singer, 2013). Specifically, individuals who had their rSMG stimulated switched perspectives between an EEB to an 'other' perspective. Stimulation of the rSMG through

implanted electrodes has been reported to induce a sudden shift in perspective, through an out-of-body experience or 'other' experience. The stimulation produced the feeling of disembodiment without the characteristic elevated and distanced visuospatial perspective reported in near death circumstances (De Ridder, Van Laere, Dupont, Menovsky, & Van de Heyning, 2007). This may be triggered by an altered integration of multisensory information, which is processed in the rSMG (Blanke & Mohr, 2005).

Fixation on old solutions or ideas can be a key barrier to insight. Shifting to a more associative mode of thought may facilitate escape from fixation and the ushering forth new perspectives (Gabora, 2010). Participant responses were categorized into insight and noninsight solution types, with the insight answers showing similar activation in the parietal lobe, which includes this studies ROI the rSMG (Subramaniam, Kounios, Parrish, & Jung-Beeman, 2009). A proposed mechanism for facilitating insight in creative problem solving is the fluid shift between cognitive processes, similar to the purposed shift in social cognition that shifts a participant's egocentric perspective to another's perspective. Specifically, creative problem solving may be facilitated by shifting along the spectrum from associative thought to analytic thought (Gabora, 2000, 2003).

Compassion-based training techniques facilitate sudden switches in perspective, limiting egocentric bias, and generating a greater sense of interconnection activating prosociality systems(Lutz, Brefczynski-Lewis, Johnstone, & Davidson, 2008). Recently rSMG has been implicated in switching of implicit perspectives and when activated limiting egocentric bias (Silani et al., 2013). The



rSMG is a part of an attentional 'circuit breaker,' the ventral frontoparietal network which is largely lateralized to the right hemisphere (Corbetta & Shulman, 2002). This network detects salient cues in the environment, and disengages top-down attentional resources towards behaviorally relevant stimuli. An attentional circuit breaker mechanism, through the spontaneous switch of attentional resources, could be used to examine internal or external insight-related salient stimuli such as a piece of emotionally relevant information about oneself.

There are similarities when contrasting the neural correlates of the top-down strategy of cognitive reappraisal to an affect attention bias that facilitates insight and acceptance. Specifically, the SMG has been shown to be recruited by a mindfulness group while regulating negative emotional stimuli compared to a group employing reappraisal (Opialla et al., 2014). Other contemplative populations have shown similar activation in the rSMG when compared to top-down prefrontal recruitment in healthy controls when being presented with emotionally eliciting stimuli (Wadden et al., 2015). A meta-analysis suggests that experienced meditators in practicing various styles of meditation maintain effortless cognitive processes such as sustained attention by recruiting the rSMG instead of relying on top-down frontal activation like their novice counterparts (Tomasino, Fregona, Skrap, & Fabbro, 2012). Therefore, it is important to conceptualize an alternate emotion regulation strategy that reinforces acceptance through recruiting bottom-up attentional resources with latent prefrontal recruitment.

## **rSMG Activated by Yoga Practitioners During Emotion Eliciting Stimuli**

A previous study used a task-based fMRI block design in which emotionally evoking and emotion-neutral video clips were presented. In RA, the presentation of emotionally evoking video clips activated the right middle frontal gyrus (rMFG) and precentral gyrus when compared to YP. In YP, the presentation of the emotionally evoking video clips activated the right anterior supramarginal gyrus (rSMG), postcentral gyrus, and the left superior parietal lobule when compared to RA (Wadden et al. 2015). In the YP group compared to the RA group the predominate parietal activation in the FPN is characteristic of affect attention bias compared to the RA's characteristic activation of frontal resources, indicating influences of goal directed action (Buschman & Miller, 2007; Ptak, Camen, Morand, & Schnider, 2011). The rMFG, otherwise referred to as the DLPFC, has been implicated in the top-down regulation of emotions (Kohn et al., 2014).

The rSMG, a key structure within prosociality system, has been linked to overcoming an emotional egocentric bias during a social judgment task (Silani et al., 2013) and is an area activated during compassion meditation during the regulation of emotions (Lutz, Brefczynski-lewis, Johnstone, & Davidson, 2008). The activation of the rSMG, by the YP group over goal-directed frontal regions, may indicate an affect attention bias emotion regulation strategy that bypasses the negative appraisal and subsequent emotion generation process. The rSMG is implicated in the prosociality system and the elimination of the egocentric bias. The affect attention bias may have shifted the self-referential experience of a video clip to an

allocentric experience, whereby individuals center their attention and actions on other people; therefore moderating the need for reappraisal or suppression of emotions.

There is support for contemplative practices activating top-down and bottom-up emotion regulation strategies (Chiesa, Serretti, & Christian, 2013). YP lack of top-down prefrontal recruitment with low autonomic arousal during emotionally eliciting video clips may affect attention bias. By eliminating the need for reappraisal or suppression the typical strategy of top-down regulation of emotions through PFC activation becomes unnecessary.

### **Compassion Meditators Couple rSMG and Precuneus During the Presentation of Emotionally Eliciting Clips**

At rest expert and novice compassion meditators showed greater activation in the rSMG and the PCC/Prec in response to sounds during compassion than when at rest, with experts having greater right lateralization (Lutz, Brefczynski-lewis, et al., 2008). The activation of the rSMG indicates that compassion meditation may enhance emotion sharing and perspective-taking. In addition to the rSMG, the right Inferior Frontal Gyrus (IFG) commonly referred to as the VLPFC showed greater activation for expert meditators. The greater overall activation of the FPN network in experts compared to novices indicates that expert meditators have a greater affect attention bias towards suffering of others (Lutz, Brefczynski-lewis, et al., 2008). During rest, expert compassion meditators had more active rSMG and Precuneus regions during the rest condition than the meditation condition prior to the

personation of the sound eliciting compassion. Intensive meditation training has been shown to influence emotional responses to suffering, with self-reported sympathy – not sadness or distress - predicting greater facial displays of sadness over controls (Shaver et al., 2012).

## **Chapter Two: The Present Study**

The goal of this study is to characterize the functional connectivity of brain regions during resting in YP and RA groups and investigates any differences in brain morphology between groups. Specifically, in whole brain resting state we anticipated a lower activation of frontal regions in YP when compared to RA (Brefczynski-Lewis, Lutz, Schaefer, Levinson, & Davidson, 2007). While explicitly examining functional connectivity at rest between the rSMG seed region and other brain regions, YP is anticipated to show increased functional connectivity with the PCC/Prec when compared to RA (Lutz, Brefczynski-Lewis, et al., 2008; Tomasino et al., 2012). Additionally, increased function connectivity between the FPN, as shown by greater functional coupling between the rSMG seed region and other parts of the FPN, should be negatively correlated with depression scores in YP when compared to RA (Opialla et al., 2014; Shaver et al., 2012; Tomasino et al., 2012). Finally, due to increased functional activation in the rSMG in the YP group when compared to RA, an increase in cortical thickness in YP when compared to RA is anticipated (Wadden et al., 2015).

### **Specific AIMS**

1. To investigate the impact of yoga practice on brain structure and resting state brain activity.

### **Hypotheses**

1. There is a difference between yoga practitioners and recreational athletes in resting-state whole brain activation.

2. There is a difference between yoga practitioners and recreational athletes during rest in the network formed by a seed region in the rSMG.

3. Functional coupling between the network formed by a seed region in the rSMG in yoga practitioners is negatively correlated to depression scores.

4. There is a difference between yoga practitioners and recreational athletes in cortical thickness at the rSMG.

## **Chapter Three: Methodology**

### **Participants**

Twenty-two participants, aged 19-60 years were recruited for a previous study: 19 YP and 12 RA. All participants were screened and free of contraindications to MRI, psychiatric or neurodegenerative disorders, and neurological/muscular deficits affecting vision, oculomotor control, or manual control. Participants were excluded if they had a recent history of substance abuse or were taking prescription medication known to alter autonomic nervous system activity (e.g.,  $\beta$ -blockers, ACE inhibitors). Prior to undergoing imaging procedures, all participants completed several questionnaires for the purposes of informing physical activity levels, personality characteristics, and yoga experience.

### **Material and methods**

1. A whole brain ICA analysis was performed, comparing differences in functional connectivity within multiple resting state components between groups (YP, RA).

2. A seed region representing the rSMG was created using SPM anatomy toolbox (software package). A seed region allows a specific anatomical space of interest to be defined during the analysis to measure correlations between that region and all other brain regions. A previous study showed that the rSMG area was significantly more active during emotion regulation task in the YP group (Wadden et al., 2015). By selecting this brain region, we are able to compute any or all brain

regions that formed a non-directional network with the seed region that was defined. Resting state functional connectivity was evaluated within the defined Region of Interest (ROI) by applying an Independent Component Analysis (ICA) using GIFT (software package).

3. In a follow-up analysis, we examined the relationship between self-report behavioural measures, biomarker data and connectivity within the resting state networks. Our behavioural measures include; levels of Metabolic Equivalents of Task (METs), Mindful Attention Awareness Scale (MAAS), Cohen's Perceived Stress Scale (PSS), the short-form Depression Anxiety Stress Scale (DASS), and Relaxation Inventory.

4. To evaluate the relationship between structure and function, the cortical thickness of the rSMG was extracted using FreeSurfer (software package) and was correlated to functional connectivity within the rSMG during resting state within groups. Between groups, the cortical thickness of a priori ROIs observed to be important during ER from our previous study was compared between YP and RA.

## **Questionnaires**

Participants completed a battery of questionnaires prior to MRI testing. Firstly, participants provided information as to the intensity, minutes per week, sessions per week, and number of years engaged in any specific physical activities in. These details allowed for the calculation of the metabolic equivalents of task (METs) for



total physical activity completed in a week, based on a compendium MET values for physical activities: tracking guide (Ainsworth et al. 2011).

Next, the Mindful Attention Awareness Scale (MAAS) was self-administered to characterize groups on levels of mindfulness. The MAAS is a validated measurement tool that indexes the frequency in which a person demonstrates mindfulness during day-to-day life.

To classify participants' day-to-day experiences of stress over the past month, Cohen's Perceived Stress Scale (PSS) was used. This validated tool measures how stressful individuals appraise daily situations to be. To assess depression, anxiety, and stress over the past week, the short-form Depression Anxiety Stress Scale (DASS) was utilized. This scale has been validated against both its long-form version and other existing anxiety scales. The Relaxation Inventory, a validated, self-administered tool comprised of three scales, measuring participants' levels of day-to-day relaxation (psychological) and tension (physiological), was employed. A total, summated, score was calculated for relaxation; higher indicating greater day-to-day relaxation. Finally, after completing the above questionnaires participants proceeded to the imaging component of the study.

### **Functional magnetic resonance imaging**

The blood oxygenation level dependent (BOLD) response was collected to measure functional activity within each subject's brain. Measurement of the BOLD response is based off of this cerebral blood flow and oxygen use (Ogawa, Lee, Kay,

& Tank, 1990). The T2 decay magnetic resonance signal component was used and exploited because it was influenced and sensitive to the presence of the deoxygenated hemoglobin (McRobbie, Moore, Graves, & Prince, 2006). By applying a dephasing gradient field at standard field strengths (1.5T and 3T) we exploited that sensitivity to the T2\* relaxation time to identify the relative amount of deoxygenated hemoglobin within brain tissue. We then use the BOLD response as a proxy for electrophysiological activation in the brain during analysis.

### **MRI acquisition**

A Philips Achieva 3.0 T whole-body MRI scanner (Philips Healthcare, Andover, MA, USA), with an eight-channel sensitivity encoding head coil (SENSE factor = 2.4) and parallel imaging, was used for all imaging. The following scans were collected during the scanning protocol: 1) high-resolution T<sub>1</sub>-weighted anatomical scan (T<sub>R</sub> = 7.4 ms, T<sub>E</sub> = 3.7 ms, flip angle  $\theta = 6^\circ$ , FOV = 256 mm, 160 slices, 1 mm thickness, scan time = 3.2 min); and 2) resting-state fMRI data was collected as echo-planar images, using a single-shot, blipped gradient-echo echo-planar pulse sequence (T<sub>E</sub> = 30 ms, T<sub>R</sub> = 2.0 s, flip angle  $\theta = 90^\circ$ , FOV = 256 mm, 64 mm × 64 mm).

### **Resting state fMRI and networks**

Resting state fMRI was gathered by BOLD signal recorded while subjects are explicitly asked to not perform specific thoughts or experimental tasks. Resting state scans were collected over seven minutes with eyes open and visually fixated on a cross. All resting state analysis is based on spontaneous low frequency fluctuations

(LFF) (<0.1 Hz) in BOLD response (Biswal, Zerrin Yetkin, Haughton, & Hyde, 1995). The relationship between BOLD LFF and electrophysiological measurements have produced a correlation between the power coherence of epidural EEG in rats and the functional connectivity between the bilateral primary somatosensory cortex (Lu et al., 2007).

## **MRI analyses**

### **MRI preprocessing in SPM8**

fMRI data was processed and analyzed using statistical parametric mapping (SPM8) software (Wellcome Department of Cognitive Neurology, University College London, London, UK). Images were realigned and normalized using the SPM templates. The normalized images of 3 mm × 3 mm × 3 mm was smoothed by a FWHM 8m Gaussian kernel.

### **Outline GIFT Whole Brain ICA Processing Steps**

A common method of analyzing fMRI resting state data is through Independent component analysis (ICA), a data-driven approach that allows the researchers to analyze the whole brain instead of being constrained to specific anatomical seed regions. ICA analysis was used to transform the data into a linear combination of statistically independent components (Erhardt et al., 2011). Each component produced was a spatial map associated with coherent fluctuations within part of the brain with some being noise and others being true resting state networks. Inspection of the spatial maps then sorted the noise and resting state neural network

components; however, this is highly influenced by reoccurring patterns from previous works spatial maps. Through analysis, many reoccurring patterns of neural activity have been identified and organized into functional networks either being task-positive or task-negative.

ICA of the same resting-state fMRI data sets was performed using the GIFT toolbox, v1.3h (<http://www.nitrc.org/projects/gift>) implemented in MATLAB (MathWorks, Massachusetts, U.S.A). Individual ICA components and corresponding time courses was computed from the individual data. The InfoMax group-ICA algorithm was then applied. The number of predefined ICA components was set to 26 (Calhoun, Adali, Pearlson, & Pekar, 2001). Independent components (ICs) that are common for the entire subject group and resemble resting-state functional networks were identified through a threshold of voxel-wise t-maps and visual examination of the spatial distribution patterns. The resulting set of images can be used in SPM to do multi-group comparisons. Next, group, second-level, *t*-tests for YP and RA groups were performed. To identify clusters of significant activation, a minimal cluster size of 5 was used and voxel-wise threshold of  $p < 0.005$ , uncorrected for multiple comparisons.

### **Outline GIFT Constrained ICA Processing Steps**

Using SPM8 Anatomy Toolbox (software package), a spatially constrained composite mask of the anatomical ROI rSMG was applied to subject images. Then ROIs were downsampled using MRICron (software package). Parameter files were then run through GIFT (software package) for a constrained ICA analysis. The

resulting set of images were used in SPM to do multi-group comparisons. Finally, group, second-level,  $t$ -tests for YP and RA groups was performed. To identify clusters of significant activation, a minimal cluster size of 5 was used and voxel-wise threshold of  $p < 0.005$ , uncorrected for multiple comparisons.

### **Outline FreeSurfer Processing: Cortical Thickness and Volume**

Reconstruction of cortical surfaces was done using the FreeSurfer (software package). Firstly, correction for intensity variations due to magnetic field inhomogeneities, non-brain tissues was removed from the T1 normalized images using a hybrid watershed/surface deformation procedure. The brain was segmented using the signal intensity and geometric structure of the gray-white interface. Each hemisphere was automatically disconnected from the other and from the mesencephalon, resulting in two binarized white matter volumes. The surface of each white matter volume was tessellated with a triangular mesh, and deformed to obtain a smooth and accurate representation of the gray-white interface. The surface topology was automatically corrected, with the inflation retaining the shape and metric properties of the original gray-white interface, leading to a representation where the whole cortical surface is visible. Using a name database, parcellation of the entire cortex was divided into sulcal and gyral cortices depending upon the values of local mean curvature and average convexity obtained from the reconstructed cortical surfaces output from FreeSurfer (software package). Then each vertex of the cortical surface will automatically be assigned an anatomical label from the name database.

## Statistical analyses

Significance level was set at  $p < 0.05$ , for all parametric statistical tests. One-way analyses of variances (ANOVAs; Factor = Group: YP, RA) was performed on all behavioral measures including: levels of Metabolic Equivalent of Task (METs), Mindful Attention Awareness Scale (MAAS), Cohen's Perceived Stress Scale (PSS), the short-form Depression Anxiety Stress Scale (DASS), and Relaxation Inventory.

Scatter plots of first-level individual data was graphed with whole-brain resting-state regions and behavioral measures. Then, scatter plots of first-level individual data was graphed with ROI resting-state regions and behavioral measures. Next, Pearson's correlation was run with brain areas of significant activation in whole brain and ROI resting-state areas, METs, MAAS, Cohen's Perceived Stress Scale (PSS), the short-form Depression Anxiety Stress Scale (DASS), and Relaxation Inventory.

Separate Univariate ANOVAs (Factor = Group: YP, RA) was performed on cortical thickness, volume and area for the rSMG with age as a covariate.

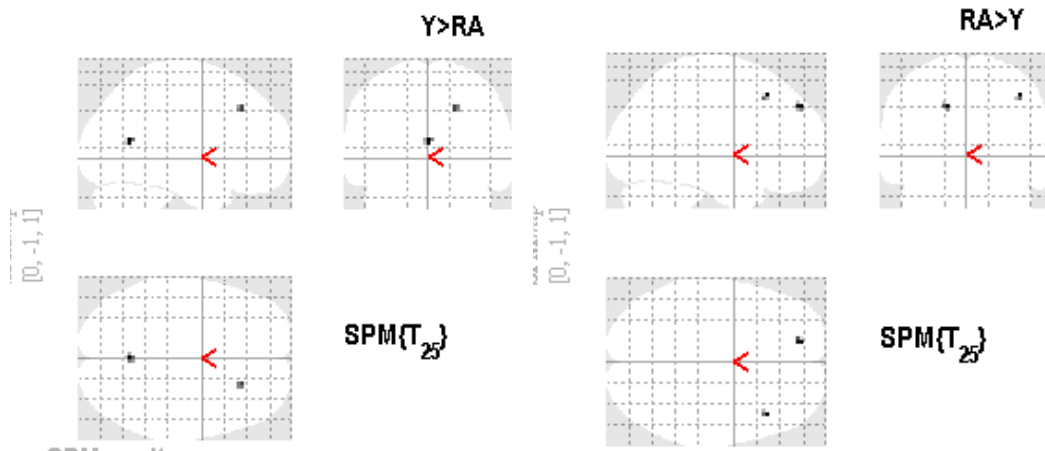
## Chapter Four: Results

### Whole brain activation during rest

The YP group activated clusters of voxels in the L Precuneus and R Superior Frontal Gyrus. YP group activation of the precuneus is interesting as the posterior cingulate/precuneus (PCC/PCu) has been implicated in the default mode network and linked to mental states of controlling and distraction (Garrison et al., 2013).

The RA group activated clusters of voxels in the Left Frontal Pole and R MFG. Previous resting state analysis comparing contemplative experience levels revealed greater functional connectivity within the prefrontal cortex for novices, as shown by activation in the L Frontal Pole and R MFG in the RA group.

**Figure 3: Whole Brain Resting State Graphical Output**



**Table 1: Whole Brain Resting State**

Anatomical Region	Cluster size (mm <sup>3</sup> )	Talairach			MNI			t- max
		X	Y	Z				
<b>A.YP&gt;RA Whole Brain Resting State</b>								
L Precuneus	27	0	- 62	21	0	- 58	16	4.26
R Superior Frontal Gyrus	21	21	28	45	21	32	40	4.02
<b>B. RA&gt;YP Whole Brain Resting State</b>								
L Frontal Pole	21	- 15	53	40	- 15	53	40	4.07
R Middle Frontal Gyrus	15	42	29	46	42	26	49	4.04

**Brain activation during rest using the R Supramarginal Gyrus as a Region of Interest**

The YP group activated clusters of voxels in the L Superior Frontal Gyrus, R Precentral Gyrus, and R Precuneus. Previous resting state analysis comparing contemplative experience levels revealed greater connectivity between the



precuneus and frontal regions as shown by activation in the L Superior Frontal Gyrus, R Precentral Gyrus, R Precuneus Gyrus in the YP group.

The RA group activated clusters of voxels in the R Superior Medial Gyrus, R Lingual Gyrus, and L Thalamus. Previous resting state analysis comparing contemplative experience levels have shown greater functional connectivity within the prefrontal cortex for novices as shown by activation in the R Superior Medial Gyrus, R Lingual Gyrus, L Thalamus in the RA group.

**Table 2: ROI ICA of rSMG**

Anatomical Region	Cluster size (mm <sup>3</sup> )	Talairach coordinates			MNI			t-max
		X	Y	Z				
<b>A. YP&gt;RA rSMG ROI</b>								
R Precuneus	69	18	-62	36	18	-58	31	6.21
R Precentral Gyrus	21	57	4	45	57	8	40	3.92
L Superior Frontal Gyrus	21	-21	52	21	-21	56	16	5.39

Anatomical Region	Cluster size (mm <sup>3</sup> )	Talairach coordinates			MNI			t-max
		X	Y	Z				
<b>B.RA&gt;YP rSMG ROI</b>								
R Superior Medial Gyrus	96	9	40	60	9	44	55	6.87
R Lingual Gyrus	27	21	-71	-6	21	-67	-11	4.05
L Thalamus	15	-6	-26	18	-6	-22	13	3.79

**Follow-up Correlation Analysis of Resting-State Whole Brain and ROI Activation with Behavioral Measures – PSS and depression**

Pearson’s correlation was calculated for specific variables to test for hypothesized relationships. As we are most interested in the adaptive nature of emotional regulation strategies, our follow-up correlation analysis will focus on the relationship between BOLD signal in clusters and PSS behavioral measure.

Within whole brain resting state the YP group showed greater BOLD activation within the PCu, a hub for default mode activity, and an area associated with effortful control over self-referential processing (Garrison et al., 2013). As these results indicate, activation of a cluster related to maladaptive emotion regulation

strategies, we hypothesized that there was a positive relationship with BOLD signal in the PCu cluster and stress, measured by the PSS.

A Pearson Correlation was computed to assess the relationship between whole brain resting state PCu activation and PSS. There was a no significant positive correlation at the  $p < .05$  significance level between the two variables [ $r = .273$ ,  $n = 27$ ,  $p = .169$ ]. Overall, there was no relationship between PCu activation and perceived stress.

The rSMG has been experimentally shown to lower the egocentric bias (Silani et al., 2013) and the posterior cingulate cortex/precuneus (PCC/PCu) positively correlates with self-referential processing (Brewer et al., 2011; Brewer, Garrison, & Whitfield-Gabrieli, 2013; Garrison et al., 2013). We hypothesized greater connectivity within the rSMG-PCC/PCu represents an adaptive emotional regulation strategy by altering self-referential processing thereby overcoming the egocentric bias. We predicted functional connectivity between the PCu and the rSMG was negatively related to depression.

A Pearson Correlation was computed to assess the relationship between connectivity within the rSMG-PCC/PCu and depression. There was a significant negative correlation at the  $p < .05$  significance level between the two variables [ $r = -.408$ ,  $n = 27$ ,  $p = .035$ ]. Overall, there was a moderate, negative correlation between connectivity within the rSMG-PCC/PCu and depression. Increases in connectivity within the rSMG-PCC/PCu were correlated with decreases in rating of depression.

## **Structural Analysis Results**

Two-way ANOVAs were conducted on comparing YP and RA's cortical thickness, volume and area in the rSMG while controlling for age. We expect to see differences in any of the three measurements due to the differences in functional activity in YP and RA groups.

## **Structural Results**

A two-way ANCOVA was conducted to determine if there was a statistically significant difference between RA and YP groups for cortical thickness in the rSMG controlling for age. The groups were not different (RA: M = 2.80, SD = .184) (YP: M = 2.83, SD = .155) ( $F(1, 32) = .468, p = .499$ ).

## Chapter Five: Discussion

The study of resting state activity has become a widely accepted means of facilitating understanding of default activity in the brain (Raichle et al., 2001). During rest, whole brain activation in the YP group displayed greater functional integration within midline structures, related to the DMN, and the right PFC, related to the FPN, compared to RA group. This greater functional integration between the DMN and FPN has been shown to improve emotional regulation (Bressler & Menon, 2010) and affect attention bias (Todd et al., 2012). Increased activation of midline structures is associated with increases in mind wandering, self-referential processing, and unhappiness (Raichle et al., 2001).

Attentional training techniques recruit attentional systems that have anti-correlative and correlative characteristics with the DMN (Fox et al., 2005). Subjects showed decreased coupling between the R IPL and the PCC during self-referential thought when compared to empathic thought about others (Van Buuren, Gladwin, Zandbelt, Kahn, & Vink, 2010). As the R IPL structurally encompasses the rSMG and the PCC is functionally and structurally connected to the PCu, this shows similar coupling as our YP group in our ROI analysis. Indicating that coupling between the parietal cortex and the default mode occurs when participants are thinking of others when compared to egocentric thought. Researchers have reported greater functional connectivity between the PCu/PCC and attentional networks in experienced meditators at baseline, indicating greater cognitive control over the DMN (Brewer et al., 2011; V. A. Taylor et al., 2013). A group using mindfulness-based strategies compared to cognitive reappraisal for emotional regulation reported similar results

as our YP group with greater activation in the Left DLPFC and bilateral SMG (Opialla et al., 2014). These results are similar to our findings of greater functional connectivity between the ROI rSMG and the left DLPFC, R Precentral Gyrus and the PCu/PCC. Individuals with high levels of cortisol show decreased coupling of the L PFC and right parietal cortex (Schutter, Honk, Koppeschaar, & Kahn, 2002), depressive symptoms (Holsboer, 2000) and heightened egocentric bias (Adólfssdóttir, Sørensen, & Lundervold, 2008). By stimulating activity in left prefrontal and right parietal regions through TMS these depressive symptoms have been reduced (George et al., 1995; George, Lisanby, Avery, McDonald, & Durkalski, 2014; Steppel, Pascual-Leone, Basser, Hallett, & Post, 1996; van Honk, J.L.G. Schutter, Putman, de Haan, & d'Alfonso, 2015). Coupling of the rSMG may modify habitual patterns of self-referential thought such as rumination, facilitated by habitual attentional training techniques leading to a modification to the affect attention bias (Cavanna & Trimble, 2006; Kuehner, Huffziger, & Liebsch, 2009; Opialla et al., 2014; Ptak, 2012; Todd et al., 2012; Tomasino et al., 2012). The moderate negative correlation [ $r = -.408$ ,  $n = 27$ ,  $p = .035$ ] between the connectivity within the rSMG-PCC/PCu and depression support the integration of the FPN and the DMN as a key mechanism for improved emotional regulation.

There was no relationship found between depression and the ROI areas activated significantly more in the recreational athlete group, suggesting that the ROI rSMG network formed by the RA group has no effect on depression.

No significant structural differences in cortical thickness were found between the RA and YP groups in the rSMG. As brain areas are not recruited in isolation, this

may indicate that subtle neural network differences instead of exclusive recruitment of the rSMG may produce differences in basic psychological processes such as emotion regulation. For example athletes may predominately recruit the FPN and rSMG for regulating visual attention of the external world during exercise, while yoga practitioner's activities recruit the integrative aspects of the FPN with other networks.

Exercise's benefits to physical and mental well being are well documented (Babyak et al., 2000; Carek, Laibstain, & Carek, 2011; Long, BC, 1995; Ross & Thomas, 2010; Salmon, 2001; Scully, Kremer, Meade, Graham, & Dudgeon, 1998; Ströhle, 2009). Though the research design compared recreational athletes against yoga practitioners, exercise and yoga are seen as complementary practices that have cumulative beneficial effects (Ross, Thomas, & Ph, 2010).

## **Chapter Six: Conclusion**

This research provides evidence that contemplative practices such as yoga, over repeated practice and time, have the ability to change functional activation within their population at rest. These functional differences indicate a relationship between YP and brain areas associated with affect attention bias and prosociality. These mindful mental processes may facilitate a distinct bottom-up emotional regulation strategy leading to positive improvements in mood and stress. Future work is needed to define a significant causal relationship between acceptance and non-acceptance-based emotional regulation strategies and their underlying neural correlates.



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