PSYCHOPHYSIOLOGICAL AND
METABOLIC CHANGES WITH
YOGA PRACTICES

A thesis submitted in fulfillment of the requirements for
the degree of Doctor of Philosophy

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Psychophysiological and Metabolic Changes with Yoga Practices

Declaration by Candidate

I hereby certify that:

(a) Except where due acknowledgment has been made, the work embodied in this thesis is the result of original research done by the candidate alone;

(b) The work has not been submitted previously, in part or as whole, to qualify for any other academic award;

(c) The content of this thesis is a result of work which has been carried out since the commencement date of the approval program;

(d) Any editorial work paid or unpaid, made third party acknowledged;

(e) Ethics procedures and guidelines have been followed;

Anupama Tyagi

Date: 25.11.2014
ध्यानमूलं गुरुमूलं गुरुपूदम् ।
मन्त्रमूलं गुरुस्वाक्यं मोक्षमूलं गुरूकूपा ॥

The Root of Meditation is the Form of the Guru;
The Root of Worship is the Feet of the Guru;
The Root of Mantra is the Words of Guru;
The Root of Liberation is the Grace of Guru.
LIST OF PUBLICATION ARISING FROM THIS THESIS

Peer Reviewed Publications


Under Peer Review


• Tyagi A, Cohen M, Linda J, Yoga and Heart Rate Variability: A Systematic Review, Applied Psychophysiology and Biofeedback.
Oral and Poster Presentation


Dedication

The long journey of completing this thesis originated from the fascination with diligent yoga practices and yoga experience that came initially from my first Yoga guru, my mother Sheela Rani Gupta. I would therefore like to dedicate this thesis to my mother.
Acknowledgement

I would never have been able to accomplish this milestone without extended support and sincere endeavors of my supervisors, Prof Marc Cohen, Dr. Shirley Telles and Dr. Linda Jones. First and foremost, I express my deepest gratitude to my senior supervisor Prof. Marc Cohen, for extending continual support throughout my candidature academically and emotionally. I thank him for all my publications, encouragement of my project and his interest in promoting yoga research. I appreciate all his contributions of time, guidance and making my PhD experience productive and stimulating. I feel honor to thank Dr. Shirley Telles, for being her research student, for the guidance in collecting research data and granting me permission to use the well equipped laboratory at Patanjali Yoga Research Center, Haridwar, India. Dr. Linda Jones, you are fabulous, therefore I extend my heartfelt gratitude for your extended help in my research, guidance for thesis structure, for proof reading, for your patience and unwavering support. Thanks for the joy and enthusiasm you gave me.

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<tr>
<td>AACE</td>
<td>American Association of Clinical Endocrinology</td>
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<tr>
<td>AHA/NHLBI</td>
<td>American Heart Association/National Heart Lung and Blood Institute</td>
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<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
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<tr>
<td>ANS</td>
<td>Autonomic Nervous System</td>
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<td>AOL</td>
<td>Art of Living</td>
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<tr>
<td>BMI</td>
<td>Body Mass Index</td>
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<td>BP</td>
<td>Blood Pressure</td>
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<tr>
<td>CAN</td>
<td>Central Autonomic Network</td>
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<tr>
<td>CHD</td>
<td>Coronary Heart Diseases</td>
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<tr>
<td>COPD</td>
<td>Chronic Obstructive Pulmonary Diseases</td>
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<tr>
<td>CM</td>
<td>Cyclic Meditation</td>
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<tr>
<td>CNS</td>
<td>Central Nervous System</td>
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<td>CVD</td>
<td>Cardiovascular Diseases</td>
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<td>DM-II</td>
<td>Diabetes Mellitus II</td>
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<tr>
<td>ECG</td>
<td>Electrocardiogram</td>
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<tr>
<td>EGSIIR</td>
<td>European Group for the Study of Insulin Résistance</td>
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<tr>
<td>FDA</td>
<td>Food and Drug Administration</td>
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<tr>
<td>GABA</td>
<td>Gama-Amino Butyric Acid</td>
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<tr>
<td>HR</td>
<td>Heart Rate</td>
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<td>HRV</td>
<td>Heart Rate Variability</td>
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<tr>
<td>IDF</td>
<td>International Diabetic Federation</td>
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<tr>
<td>ISKCON</td>
<td>International Society of Krishna Consciousness</td>
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<tr>
<td>MAST</td>
<td>Mental Arithmetic Stress Test</td>
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<td>MBSR</td>
<td>Mindfulness-Based Stress Reduction</td>
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<td>MetS</td>
<td>Metabolic Syndrome</td>
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<tr>
<td>NCCAM</td>
<td>National Center for Complementary and Alternative Medicine</td>
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<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>NCEP-ATPIII</td>
<td>National Cholesterol Education Program- Adult Treatment Panel III</td>
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<td>NIH</td>
<td>National Institute of Health</td>
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<tr>
<td>OC</td>
<td>Oxygen Consumption</td>
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<td>POMS</td>
<td>Profile of Mood States</td>
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<td>PNS</td>
<td>Parasympathetic Nervous System</td>
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<tr>
<td>RR</td>
<td>Respiratory Rate</td>
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<tr>
<td>RSA</td>
<td>Respiratory Sinus Arrhythmia</td>
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<td>ROS</td>
<td>Reactive Oxygen Species</td>
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<tr>
<td>SNS</td>
<td>Sympathetic Nervous System</td>
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<td>TM</td>
<td>Transcendental Meditation</td>
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<td>WHO</td>
<td>World Health Organisation</td>
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Thesis Abstract

**Background:** Stress results from a homeostatic burden that requires an adaptive response. Responses to stress include ‘reactivity’, ‘recovery’ and ‘restoration’, with the type of response mediating the relationship between stress and disease. The inability to recover after a stressful event or maladaptation to stress due to reduced adaptive capacity and/or psychophysiological inflexibility contributes to allostatic load and the development of chronic disease such as metabolic syndrome and its associated features.

Yoga encompasses an ancient system of practices that enhance synchrony between the mind, body and breath and fosters psychophysiological resilience through a combination of stimulating and relaxing practices. While the practice of yoga was originally designed to enhance personal and spiritual development, many practices have been shown to alter physiological and psychological processes in ways that reduce the risk of disease.

**Aims:** The major objectives of this thesis are:

To investigate the effects on yoga of blood pressure (BP) regulation, cardiovascular risk factors, oxygen consumption (OC) and heart rate variability (HRV)

To examine the metabolic and cardio-autonomic responses to stress in regular yoga practitioners, non-yoga practitioners and people with metabolic syndrome

To investigate the mood states and flow states associated with the practice of yoga in yoga practitioners, non-yoga practitioners and people with metabolic syndrome

**Methods:** A series of five studies were undertaken including systematic reviews of yoga and blood pressure, oxygen consumption and heart rate variability and two explorative interventional studies. The systematic reviews categorized studies according to the type of yoga practice and the experimental design. The
interventional studies compared the cardiovascular, metabolic and autonomic responses to mental arithmetic stress and various yoga practices in regular yoga practitioners, non-yoga practitioners and individuals with metabolic syndrome.

**Results/Discussion:** The systematic reviews suggest that different yoga practices have profound effects on blood pressure, oxygen consumption and heart rate variability, with changes that suggest increased resilience and resistance to stress and the features of metabolic syndrome. These reviews also suggest that regular yoga practitioners have an enhanced homeostatic capacity and an ability to exert extraordinary control on physiological processes and maintain homeostatic responses under extreme conditions.

The experimental study suggests that compared to non-yoga practitioners, regular yoga practitioners had a greater physiological response to mental arithmetic stress and make a faster and more complete recovery. People with metabolic syndrome on the other hand had a blunted and incomplete recovery. The experimental study also demonstrated that regular yoga practitioners had an enhanced experience of flow and positive mood states at baseline and greater increase after yoga practices compared to the other groups.

**Conclusion:** Yoga practices have a profound effect on cardiovascular, autonomic and metabolic responses that counter many of the triggers and effects of metabolic syndrome and other chronic diseases. Regular yoga practitioners appear to have greater resilience to stress with increased psycho-physiological flexibility and enhanced mood states. Yoga practices are worthy of inclusion in clinical settings to counter stress and a variety of chronic diseases such as metabolic syndrome. Further rigorous clinical trials of different yoga practices are required to justify the inclusion of yoga in clinical guidelines for specific conditions.
CHAPTER 1
Background

This section provides a brief historical and conceptual background for mind-body medicine modalities such as yoga and outlines the objectives and chapter organisation of the thesis.

1.1 Mind-Body Medicine: Historical and Modern Perspectives

It has been recognized since antiquity that people’s habits, beliefs, attitudes, physical environment and how they live all play a significant role in their health and illness. Distress is a potent indicator of external threats, and relief from distress is a basic requirement for survival. The early philosophies considered physical health and spirit were inextricable bond and conflict between external environment and the internal self was considered the major cause of affliction, suffering, pain and disease (Shroff 2011). To attain physical as well as mental wellbeing, these philosophies sought to achieve coherence, harmony and balance through fervent prayers, symbols, meditative practices and rituals (Sternberg 2000).

The common theme amongst all ancient healing and spiritual traditions is the principal of oneness. Health is considered holistic, and entities and systems in the universe, including humans, are part of the unified whole that cannot be understood by isolated examination of its separate parts (Shroff 2011). The modern derivation of the word health arises from the Greek word holos for whole. This suggests that health is a positive state, not merely the absence of diseases, and that health is tied closely to familial, social, cultural, environmental and spiritual factors. In Eastern philosophies the concept of wholeness is expressed by the word tao, which refers to harmony with nature, while the word yoga means yoke or ultimate union (Frawley 1997). Thus yoga unfolds the concept of oneness, or Samadhi, by achieving perfect harmony among the system elements through contemplative path of yoga. Swami Sataynada Saraswati defines this concept as sublime equanimity (Saraswati, S 2005).
While healing traditions in the West started from a holistic perspective, they eventually separated health into vitalistic and mechanistic paradigms. Throughout history, the line separating these two realms has not always been clear, but their philosophical perspective has generally been in opposition. The mechanistic perspective maintained the phenomena of life could be explained exclusively as the product of a complex series of chemical and physical reactions and became the dominant paradigm for the biomedical science that underpins most of the Western medicine. This reductionist approach led to the development of scientific models that vastly improved medical practices by defining, with increasing certainty, the pathophysiological basis of disease and led to the development of advanced medical technologies including biochemical and pharmaceutical sciences, medical imaging and advanced surgical techniques (Nettleton 2009). The result has been a progressively better understanding of human biology and a greatly enhanced ability to improve the outcomes of many acute diseases (Bendelow 2009). Nevertheless, with proven effectiveness for acute disorders, it has not been effective in stemming the global epidemic of stress related chronic diseases.

In contrast with the mechanistic world view, vitalists maintain that life is too well organised to be explained as a complex assemblage of chemical and physical reactions. The vitalist approach conceptualises health as a state of harmonious balance between fundamental forces or elements. Ill-health, on the other hand, reflects an imbalance in the forces or elements. The eastern healing traditions, such as traditional Chinese medicine, Ayurveda and yoga, all of which focus on functional rather than physical anatomy and the flow of so-called vital energy, ‘chi’ or ‘prana’ (Saraswati, N 2005).

Yoga intertwined in the rich tapestry of ancient Indian culture expound coherence of mind, body and breath and strongly advocates that physical distress can affect mind adversely and imbalance vital force that can lead to illness (Frawley 1997). Thus Yoga stresses that the body is adversely affected by the imbalance in ‘prana’ and recommends to consciously mobilise ‘prana’ through ‘pranayama’ or breathing practices (Saraswati, S & Saraswati 2005) and in doing so, unite the mind and body.
Presently, the construct of mind-body medicine including yoga with important consideration such as cost-effectiveness, self-regulation, which facilitate integrity of system organs and address functional links between brain/mind and body and maintain general health, is widely accepted phenomenon. Further, in response to continued growth in the use of mind–body medicine, the National Centre for Complementary and Alternative Medicine (NCCAM, USA) proposed a systematic definition for mind–body medicine that is outside the scope of Western biomedicine (Moss 2003 Pg 58).

Mind-body medicine focuses on the interactions among brain, mind, body and behaviour, and the powerful ways in which emotional, mental, social, spiritual and behavioural factors can directly affect health. Mind-body medicine typically focuses on intervention strategies that are thought to promote health, such as relaxation, visual imagery, meditation, yoga ... Spirituality and prayer (NCCAM 2008)

As a result, these therapies are widely being accepted in modern health care system that includes a wide range of behavioural and lifestyle interventions on an equal basis with traditional medical interventions. Several landmark publication such as The powerful placebo (Beecher 1955) and the scientific investigation, those identified that mental activities modulate physiological state of health (Benson 1975; Ornish et al. 1990; Ornish et al. 1983) and are credited to increase the multi-fold popularity of mind-body interventions. In this progression, the great contribution comes from Dr Herbert Benson, while investigating yogic mediative practices, noticed a striking physiological state, a ‘hypo-metabolic state’, that allowed control over the peripheral and central nervous system and thus coined the term ‘relaxation response’. This is the antithesis to stress response ‘fight and flight’ behaviour (Benson 1975).

The mind-body medicine involves an integral approach of behavioural modulation and aim to elicit a state of vagal dominance or relaxation (Bertisch et al. 2009) that may be particularly helpful for mental and physical issues in which psychological stress plays an important role (Park 2013). Accumulative evidence suggests that these therapies are being widely used in range of symptom conditions associated with stress and chronic diseases (Barnes, Bloom & Nahin 2008; Park 2013). The holistic healing process of these therapies either elicits the top-down mechanism or bottom-up mechanism to influence physiological system.
Whereas, the multifaceted practices of yoga have been suggested to initiate both the mechanism (Taylor, AG et al. 2010). Hence this may have far reaching effects on physiological, cognitive, emotional and behavioural states that are negatively affected by stress.

Yoga philosophy considers the greatest stress comes from fluctuations of the mind as it moves towards the things it wants or away from things it dislikes, as it runs towards future worries, or becomes mired in past mistakes. The mind is in constant motion, shifting into future obligations or past frustrations. When mind is 100% in present we experience the calmness, peace and joy that minimizes the effects of stress (Brown, Richard P. & Gerbarg 2009, Pg 55-56).

Yoga lacks a clearer definition, but importantly, the heterogeneous set of yoga practices, reflect the richness and diversity in application and its therapeutic effects have proliferated in past few decades with 10 fold increase in peer reviewed publications (Woodyard 2011). Conceivably, yoga which has cultural and philosophical conception for healing also involves corporeal aspects with symptom specific effects. The aspects, asana (physical postures) particularly appears to have positive effect on fitness and physical flexibility with secondary effect on mental state. While, pranayama (yogic breathing) and meditation/relaxation techniques may result in greater awareness, emotional and attentional precepts and calm state due to cognitive refinement (Büssing et al. 2012) serving to behavioural flexibility and improved physiological system. Thus the combinations of stimulating and relaxation yoga practices facilitate coherence among physiological system. These effects overtime may lead to upward spiral of flexibility and that in turn may enrich psychophysiological and metabolic response which efficiently can deal with stress and stress related diseases and may be incorporated in clinical practices. However these effects have never been investigated and documented previously.

1.2 Objectives of the Thesis

The overall objectives of this thesis are to explore the important role of yoga in countering stress responses and gain a deeper understanding of the therapeutic potentials of yoga that in turn influence the functional capacity of the end organ and remould several regulatory pathways. While exploring these objectives, this
thesis will focus on different dimension of stress and their relationship with psychophysiological inflexibility which is vital in stress responses- reactivity, recovery and restoration and that contributes to metabolic syndrome. Further this thesis examines the different yoga techniques that concurrently alter psychophysiological and metabolic processes. Furthermore, this thesis will explore the possible underlying mechanism that may be vital in influencing flexibility, restoration and facilitating wellbeing, longevity and health.

1.3 Evolution of the Research Questions in the Investigation

Portion of this Thesis

The specific research questions addressed in the individual studies that make up the investigation portion of this thesis evolved over the course of this research. All of the papers in the investigation portion of this thesis are either have been published or are under reviewing process. This section of the introduction describes the progression of the studies, and the evolution of the research questions addressed in this thesis to assist the reader in understanding how they are linked.

One of the initial objectives of this thesis was to investigate the assumption that yoga practices countering stress foster efficient adaptive responses and hence have effect on the cardiovascular, metabolic and autonomic regulatory activities. In contrast, stress, simultaneously affects heart rate (HR), oxygen consumption (OC), blood pressure (BP), mood and cognitive process. Inappropriate responses to stress disrupt physiological system with higher resting HR, resting, metabolic rate, and elevated BP and reduced heart rate variability (HRV). While, prolonged chronic physiological effects of stress imbalance autonomic regulatory activities resulting in allostatic load contributing to cardiac diseases, metabolic syndrome (MetS) and hypertension (HPT).

HPT, commonly known as persistent elevated BP is a major health concern which is estimated to affect 1 billion people worldwide. There is direct positive relationship between HPT, risk factors of MetS and cardiovascular diseases. While pharmacological interventions for HPT are used routinely, yet the non-
pharmacological approaches and lifestyle modifications are strongly recommended by expert panels. The first study conducted is a systematic review (with 120 studies) that investigated the effects of different techniques of yoga on HPT. This study resulted in published study, presented in Chapter 5 of this thesis titled *Yoga and hypertension: A systematic review.*

Monitoring of OC has received a great deal of interest and provides insight into overall homeostatic balance and response to stress reflecting autonomic status. Increases in OC correspond to physiological, psychological stress and chronic conditions such as features of MetS. The ability of yoga is acknowledged as promising construct in reducing stress and as adjunct to pharmacological therapy. The OC and yoga has never been subjected to review to date. The second study therefore of this thesis is systematic review (with 58 studies) investigated effects of different techniques of yoga on OC. This study resulted in a published study, presented in Chapter 6 of this thesis tilted *Oxygen consumption changes with yoga practices: a systematic review.*

High resting HR has been found to be a risk factor for cardiac diseases, while low resting HR reflects flexible autonomic regulation and HRV (which is a measure of beat to beat fluctuations of HR) is a strong indicator of sympathetic and parasympathetic processes. Yoga practices improving cardiovascular function are reported to influence autonomic activities and enhance vagal tone yet the effects of yoga on HRV has never been subjected to review. The third study therefore of this thesis is a systematic review (with 49 studies) that investigated effects of different techniques of yoga on HRV. This study is submitted and is under reviewing process and present in Chapter 7 of this thesis titled *Yoga and Heart rate variability: A systematic review.*

The results of the three systematic reviews suggest that yoga plays an influential role in modulating BP, OC and HRV, however; while many studies suggest that yoga may be effective for mitigating stress, most have relied on subjective measures and have greatly overlooked non-invasive physiological measures such as OC and HRV. These variables, which provide more accurate measures of peripheral activity and reflect vagal tone also related to higher brain activities. Furthermore, the stress literature suggests that stress reactivity and
recovery mediate the relationship between stress, health and disease yet until recently, this literature has generally ignored vagal tone and mostly examined sympathetic activity.

While research on the relationship between stress and disease is extensive, there is very little research on yoga and stress reactivity and no research on yoga and stress recovery. To determine the efficacy and validity of yoga in mitigating stress reactivity and recovery an explorative interventional study was designed that used mental arithmetic stress test (MAST) as a reliable way to induce stress and explore reactivity and recovery in regular yoga practitioners, non-yoga practitioners and individuals with metabolic syndrome.

This study with two different physiological makers of stress and health (OC and HRV) have been analysed separately and therefore has been reported in separate chapters in this thesis - Chapter 8 and 9 respectively. Of this, the study that investigated the measure of OC, mental stress and yoga practices in three groups resulted in published study and is presented in Chapter 8 of this thesis titled An Explorative study of metabolic response to mental stress and yoga practices in yoga practitioners, non-yoga practitioners and people with metabolic syndrome.

Further the data set of HRV, mental stress and yoga practices in three groups is under reviewing process and is reported in chapter 9 of this thesis titled Heart rate variability during yoga practices, mental stress in yoga practitioners, non-yoga practitioners and people with metabolic syndrome.

1.4 Organisation of the Chapters

1.4.1 The First Current Chapter is Background

Chapter 1 – Background provides the brief rational for undertaking the research in this thesis as well as provides the ground for research question.
Chapter 1
Background

1.4.2 Chapters 2-4
(Literature Review Chapters)

Chapter 2 – Stress and Mind-Body Balance provides an overview of stress as inflexibility and as mean of significant challenge to physical and mental health. This chapter further explores the dynamic balance and identifies the functional system through which mind and body system network, communicate and leads to both disease and health.

Chapter 3 – Stress and Diseases provides an overview of the literature that underpins the parallel relationship of stress, cardiovascular diseases and metabolic syndrome. Further this chapter extends the understanding of the biological mechanism of MetS. Identifying the economic burden of MetS and cardiovascular diseases this chapter explores the prevailing treatment approaches and provides the justifications for the therapeutic integrative approach of mind-body medicine contextualizing yoga as treatment for the syndrome.

Chapter 4 - Yoga and Psychophysiology examines the use of yoga as an ancient spiritual practice and a modern physical exercise. It investigates the current literature and discusses the clinical relevance of yoga practices in stress related conditions. This chapter provides the background for the intervention study.

1.4.3 Chapters 5-9
(The Investigation Portion of This Thesis)

1.4.3.1 Section 1 - Contains Three Systematic Reviews Examining the Influence of Yoga on Blood Pressure, Oxygen Consumption and Cardiac-Autonomic Control

Chapter 5 - Yoga and Hypertension: Systematic Review

Chapter 6 - Yoga and Oxygen Consumption: Systematic review

Chapter 7 - Yoga and Heart Rate Variability: Systematic Review
1.4.3.2 Section 2 - Contains Two Studies, From the Same Data Set That Explored Mental Stress and Yoga Practices in Different Population

**Chapter 8** - An Explorative Study of Metabolic Response to Mental Stress and Yoga Practices in Yoga practitioners, Non-yoga Practitioners and people with Metabolic Syndrome

**Chapter 9** – Heart Rate Variability ‘HRV’ During Yoga practices and Mental Stress in Yoga Practitioners, Non-yoga Practitioners and people with metabolic Syndrome

1.4.4 The Final Chapter Contains the Discussion and Conclusion

**Chapter 10** - Overall Discussion
2.1 Introduction

Stress has emerged as a significant challenge to both physical and mental health and this chapter specifically focuses on stress from different perspectives that ultimately leads to pathophysiological conditions.

While the notion of the mind–body split has profoundly influenced Western medicine, yet many researchers who focus on stress and its effects on the body have spoken eloquently against this split. Instead, they have promoted a discussion of mind–body interactions that focus on the complexity of the brain, nervous, hormonal and immune systems and their psychophysiological connections. Stress researchers commonly examine how mental events can exert pronounced effects on bodily processes and how a balance in autonomic regulation and flexibility in system organs is required for efficient adaptation and to maintain the dynamic equilibrium essential for survival.

The specific aims of this chapter are: (1) to explore the concept of stress and explain dynamic balance, homeostasis and allostasis as well as the distinction between acute and chronic stress to understand the health implications associated with stress; (2) to explore the understanding of stress as conceptualised by different disciplines; (3) to examine integrated model of stress that outlines the process through which anticipated or psychological stressor could be potentially harmful and lead to disease; (4) to explore laboratory induction of stress and methods to measure stress responses that may provide insight into cardiovascular, metabolic and autonomic stress responses; (5) to analyse the stress regulatory system mediating the mind/brain and periphery; and its relationship to flexibility and allostatic load. This will lay the ground for an understanding that inflexible system that reflects mind-body disintegration leads to allostatic load and further contributing to pathology such as such as cardiovascular disease, metabolic syndrome.
2.2 Concept of Stress

Stress has long been a major focus because of its influence on health. *Time* magazine’s cover story for 6 June 1983 named stress the ‘Epidemic of the Eighties’ and the impact of stress has grown over the ensuing decades. People from all places and culture experience stress and its sequelae, and maladaptation to stress alters both brain and peripheral physiology. As yet, the meaning of ‘stress’ varies across fields with no single accepted definition. Thus the concept of stress has been criticised for its lack of precision (Taylor, SE & Master 2010). The term ‘stress’ has also been questioned, as to what exactly it refers to and even some have called to abandoning the term (Aldwin 2012).

Despite there being no generally accepted definition, the concept of stress is widespread in both scientific and popular use around the world. Many disciplines have studied stress – ranging from the biological sciences such as physiology, biochemistry and neurophysiology; through the psychological science such as psychoanalysis, personality, learning theory, developmental psychology and military history (Aldwin 2012). All these disciplines appear to have a strong commonality among their approaches that are suggested to contribute to an integrated theoretical framework for understanding the role of stress in health and diseases (See figure 2.4). Each discipline focuses on an aspect of internal anticipation of threat or external challenges (physical) as stimulus or on physiological response to the stimuli such that;

They all share an interest in a process in which environmental demands tax or exceed the adaptive capacity of an organism, resulting in psychological and biological changes that may place person at risk of diseases (Cohen, S, Kessler & Underwood 1997, Pg 3).

2.2.1 Balance and Homeostasis

The idea that stress disrupts internal balance and places demands on the capacity of organisms to regulate biological functions stems from the work of Claude Bernard who is considered the father of modern physiology. Bernard stated that:
all the vital mechanics however buried they may be, have only one object: that of preserving constant the conditions of life in the *milieu interieur* (internal environment)....... it is a fixity of the *milieu interieur* which is the condition of free and independent life (Rosch 2003, Pg 235)

Bernard saw that life exists by maintaining a complex dynamic equilibrium that is constantly challenged by intrinsic or extrinsic, real or perceived adverse forces or stressors and emphasised the importance of *regulation and harmonious whole* (Cooper, SJ 2008). Bernard emphasised the dynamic and oscillatory nature of the nervous system in maintaining the parameters of the internal milieu within a limited range and contributed to knowledge of regulatory processes by describing internal secretions after identifying the existence of ductless (endocrine) glands (Langley 1973).

Bernard’s work was elaborated on by Walter Canon in the early 20th century, who coined the term *homeostasis* to refer to the complex and coordinated physiological processes that maintain steady state within a functional range. Canon explored the autonomic and endocrine responses that regulate metabolism and argued that homeostasis is maintained by self-regulating negative feedback mechanisms (i.e servocontrolled reflexes) (Cacippo & Bernston 2011), that work within certain limits and buffer the organism from changes in internal milieu. The concept of homeostasis emphasised that the sympathetic and parasympathetic branches exert opposing effects on end organ in order to maximise autonomic resources. Canon described the activities of sympathetic-adreno-medullary (SAM) system in anticipation of emergencies that enhance survival and termed the response pattern as *fight and flight* reaction. He further explained that these stress reactions precipitate a cascade of coordinated responses and mobilize metabolic resources necessary for survival (Cooper, SJ 2008).

2.2.2 Allostasis

From a modern dynamical system perspective, an organism is a complex set of circuits or subsystems working together in a coordinated fashion (a set of loosely coupled bio-oscillators) and this theory holds that stability, adaptability and health are maintained through variability in dynamic relationship among system
elements. The hallmark of dynamical system perspective is that, all regulatory mechanism are not based on negative feedback loops maintaining by a system of rigid servo-control such as baroreceptor heart rate (HR) reflexes in blood pressure (BP) regulation, as positive reverberating feedback loops also occurs. Examples such as concurrent increase in HR, BP, breath rate (BR) and cardiac output during stressful experience or activity (Cacippo & Bernston 2011).

While reshaping the homeostatic concept, Sterling and Eyer coined the term *allostasis* to describe the *maintenance of stability through change* (Sterling & Eyer 1988, Pg 631). Allostasis (See figure 2.11) involves bidirectional interaction of the whole body and brain. Accordingly allostasis entails an adaptive process and the active deviation from homeostatic level that refers to the flexible and coordinated adjustments in physiological regulatory system whereby the system set points are modified over time to meet anticipated or expected demand such as being awake, physical and mental stress (McEwen 1998b; Sterling & Eyer 1988).

Because the system operates *far from equilibrium*, it has to maintain local energy minima to minimise the energy requirements for efficient physiological function. Thus the allostatic (adaptive) system, with its several complex interdependent and interactive regulatory processes, uses the autonomic nervous system (ANS) and the involvement of the higher neural system through the hypothalamic-pituitary–adrenal (HPA) axis and cytokines in integrating broader range of homeostatic reflexes to respond to challenges and promote adaptation (McEwen 1998b).

According to this view, autonomic regulation may not be autonomic balance per se but autonomic flexibility or regulatory capacity that permits an organism to adaptively deal with changing demand. The duration of these changes is an important feature that distinguishes between adaptive and maladaptive reactions. Efficient allostatic regulation may, therefore, reflect organised variability that achieves greater flexibility in maintaining integrative regulation (both within and across autonomic, cardiovascular, metabolic, neuroendocrine and immune functions) than possible through homeostasis alone (Friedman & Alder 2011). In contrast, individuals with attenuated endogenous variability exhibit a lack of physiological, emotional and behavioural flexibility in response to environmental
demands that reflect a compromised psycho-physiological system (Porges 1992) with impaired stress responses that lead to cardiovascular and metabolic diseases (Steptoe & Kivimaki 2013; Thayer & Lane 2007).

2.2.3 Classification of Stress: Acute and Chronic

The major distinguishing characteristics of stress are its intensity (magnitude/frequency), duration (acute or chronic) and response (physiological, emotional and behavioural). A distinction is usually drawn between acute (time limited) and chronic stress (long term) with chronic uncontrollable stress generally regarded as more consequential and detrimental to wellbeing. However, there are accumulating evidences to suggest that both acute and chronic stress contribute to the development of many chronic, lifestyle related diseases. Thus, acute stress places demands on an organism beyond its ability to adapt leading to significant risk of morbidity and mortality. For example, acute stress may lead to problems in cardiac patients (Strike et al. 2004) including arrhythmias and sudden cardiac death (Kaltsas & Chrousos 2007). Similarly, chronic stress due to repetitive, severe or prolonged stressors can persist for weeks or months and manifest as chronic stress (maladaptive ramifications) that places an individual at risk of diseases (McEwen 1998b; Uchino 2007).

2.3 Stress as Viewed by Different Disciplines

While initial stress research focused on physiological responses to stress, modern research has expanded to include psychological and environmental aspects and the influence of stress on disease causation and progression. Thus, physiological stress research that focuses on the neuroendocrine and immunological reactions to stress, is complemented by psychological research that examines individual cognitive, behavioural and emotional reactions to stress as well as sociological and epidemiological research that examines the environmental challenges, including life events or experiences, that may influence disease risk (Cohen, S, Kessler & Underwood 1997). Stress research therefore stretches from cells to society.

Recently research concerning stress and health has shown increased differentiation following the identification of biological stress responses and
disease promoting mechanisms. Thus, social, psychological, behavioural and emotional factors have all been shown to influence the aetiology and pathogenesis of various diseases by altering stress responses and the functioning of bodily systems, organs and cells (Taylor, AG et al. 2010). Individual differences in resilience and stress reactions, which are the cornerstone of stress responses, have also been shown to vary across individuals, with variations in affect, i.e., individual with high levels of negative affect have been shown to have stronger and longer-lasting reactions than their more positively counterparts.

The interdisciplinary usage of the term 'stress' has led to attempts to specify the essence of stress that remains constant across varied applications of the term. One such integrative definition states that:

stress is a constellation of events, consisting of a stimulus (stressor) that precipitates a reaction in the brain (stress perception and processing) and activates physiological fight and flight systems of the body (stress responses) (Dhabhar & McEwen 1997, Pg 289).

Thus, within the broad rubric of stress, research has focused on, stress as a stimulus, stress as a process and stress as a response. Only brief overviews of these approaches are outlined.

2.3.1 Stress as Stimulus

The idea of stress as a stimulus embraces the notion that stressors come from outside the individual and that stress is inherent in events regardless of individual responses and differences. This view considers stressors as arising from specific life events and/or environmental conditions and Cohen and colleagues (1997) have portrayed it as an 'environmental stress perspective' (Cohen, S, Kessler & Underwood 1997).

The stimulus based approach views stress as a stimulus that produces a reaction and proposes that life events can be prognostic factors for illness (Lyon 2012). The central proposition of this approach is that the events precede diseases and too many life changing events in a relatively short period are correlated to impaired cognitive, emotional and behavioural responses thus
provoking psycho-physiological symptoms (Contrada 2011; Rice 2012). The major focus of this approach is identifying characteristics of the environment that promote illnesses. This has led to hundreds of scientific studies on the ability of life events and environmental stressors to predict diseases. For example, a 14-year study of daily life stressors suggests that life stress can predict the occurrence of metabolic syndrome (Chandola, Brunner & Marmot 2006).

2.3.2 Stress as Process

An alternate view of stress suggests that stress does not exist in the event but rather is a result of a transaction between a person and the environment (Lazarus & Folkman 1984). The centre focus of this model is that stress is a subjective experience arising from a combination of environmental demands (stimuli/challenges) and individual resources (coping) that are mediated by cognitive process (thoughts, attitude, and belief) and determine whether there is a positive or negative response. The most important dimension of this model is behaviour which encompasses a set of cognitive, affective and coping strategies and these are identified as a complex integrated phenomenon of appraisal or self-evaluation.

The heuristic approach of this model has been described through a prospective study in which the subjects viewed an unpleasant film depicting workers being maimed or killed by accidents occurring in the workshop. This study established the evidence that psychological and cognitive appraisal play a considerable role in stress responses (Lazarus et al. 1965).

The alternative view of this approach is associated with psychological inflexibility that stems from complex human behaviour and reflects the general tendency to experience negative emotions; distress and inability of positively regulate coping strategies. The psychological inflexibility, the diathesis of anger, mood, fear and arousal manifesting in many different ways contribute to negative affective states and inappropriate physiological functioning (Kashdan & Rottenberg 2010). A substantial body of evidence supports the idea that psychological inflexibility associated with negative stressful challenges may have negative consequences on health whereas with the right appraisal inducing positive
affective state promotes faster recovery and resilience (Pressman & Cohen 2005; Tugade, Fredrickson & Barrett 2004). These positive affective states may transforms in to pleasant positive challenges contributing to enhanced optimal performance that facilitate experience of flow (See section 4.6.1) (Csikszentmihalyi 2008).

2.3.3 Stress as Response

Stress as response refers to the individual’s physiological and psychological reactions to perceived threats. The concept of stress and physiological, cognitive, emotional and behavioural responses are intertwined and stressors and stress responses can be seen to both trigger disturbances and imbalances in the internal milieu as well as contribute to the promotion of growth, adaptation and resilience.

The response-based view of stress is attributed to Hans Seyle who described stress as a nonspecific response of the body to noxious stimuli (Selye 1956). Selye’s work focuses on physiological responses to stress and builds on Cannon’s (1932) notion of sympa-tho-adrenal changes that act as emergency fight or flight function. Selye proposed that any kind of stressor leads to the same defensive physiological activation which he called the General Adaptation Syndrome (GAS). The GAS includes well-defined stages (alarm, resistance and exhaustion) (Rice 2012).

Selye pointing out, that all stress are not deleterious and can be positive, motivating force and improve quality of life has distinguished constructive from destructive stress. These initial stress reactions is characterised by sympathetic nervous system (SNS) stimulation. He called such positive stress “eustress and debilitating excessive stress as distress (Selye 1983). Selye’s model gives special status to the HPA axis during the resistance phase, and suggests that responses that fail to fully counter a stressor result in exhaustion, and therefore compromise health, with severe or prolonged stress leading to disease and death. While Selye’s work, which pays little attention to psychological stressors or behavioural and coping factors, has been influential, it is now generally acknowledged that, in humans, physiological stress responses do not adhere to this rigid model.
(Contrada 2011; Rice 2012) and that psychological and physiological stress responses vary from person to person.

Modern research into the stress response has elaborated on the concept of ‘fight or flight’ by describing a ‘freeze’ response – or tonic immobility, which is a passive response, that is a key facet of the alarm phase. The distinction between active versus passive responses has been described by an analogy to ‘hawk and dove’ strategies (Korte et al. 2005). Hawks are proactive and bold and exhibit fight and flight responses associated with SAM activities, whereas doves favour a response style that emphasises passivity, reactivity, nonaggression and caution with the activation of HPA axis and secretion of corticotrophin releasing factors.

Tonic immobility- ‘freezing’, has received some scientific attention in recent years in reference to post-traumatic stress disorders and/or rape incidents (Schmidt et al. 2008). Recently, Taylor and colleagues (2010) suggested that in addition to the masculine style fight or flight response, there is also a more feminine ‘tend and befriend’ response. This response reflects the proclivity of females towards affiliation, cooperation and caretaking:

> Tending involves nurturant activities designed to protect the self and offspring that promote safety and reduces distress: befriending is the creation and maintenance of social network that may aid in this process  (Taylor, SE & Master 2010, Pg. 104)

Large body of literature support the notion that stress exerting pronounced effect on physiological system affects physical and psychological health with increased cardiovascular and metabolic dysfunctions (Thayer & Lane 2007). Whereas there are evidences suggesting that stress can leads to adaptation and improvements in the ways in which individuals think, manage their emotions and regulate and direct their behaviour to control their autonomic arousal and alter or decrease various sources of stress (Cooper, CL 2005).

The rich construct of mind-body medicine therapies emphasises on the conscious efforts to modulate behavioural responses that facilitate positive interpretation of environmental challenge (stressors) that further serve to shape the subjective experience associated with the event or stressor (McGrady 2007). These conscious efforts associated positive appraisal skills, positive affective state
allow greater voluntary control over autonomic and central regulatory activities. There are evidence suggesting that cultivation of positive emotional construct facilitates psychological resilience, improve cognitive activities and mood states and further results in improved health and reduced cardiovascular risk factors (Akhtar, Yardi & Akhtar 2013).

2.4 Integrative Model of Stress

Stressors that lead to fight and flight reactions and prepare the organism for immediate action are reflected in cardiovascular metabolic and autonomic activities. Repeated and prolonged sympathetic innervation alters the levels of the stress hormones that may contribute to the onset of disease (Licht et al. 2010). Cortisol acts as the key stress hormone of the HPA axis and interacts with SNS to facilitate avoidance or corrective action. While the evolutionary significance of this autonomic activation is clear, it may not always be appropriate in modern human societies. As Folkow and Neil (1971) stated:

Beyond doubt, this cardiovascular –hormonal anticipatory adjustment is of the utmost importance for survival in the animal kingdom. However, in highly developed social context, the pattern of hazards is different from that faced by the hunter-gatherer. Although in some sections of modern society is extremely perilous, contemporary challenges are often symbolic, not involving immediate physical threat or demanding mobilization for vigorous counteraction. Nevertheless, it seems that these challenges provoke much the same pattern of preparatory adjustment seen in the case of physical threat (Folkow 1971, Pg. 569).

Far from the concept of immediate mobilisation of energy resources, everyday stressors are more likely to stem from emotional, cognitive and behavioural perceptions that are reflected through worry, anxiety and ruminative self-deprecating thoughts as well as negative mood states. This observation suggests that moderate levels of arousal may be elicited repeatedly during everyday life, and that neuro-hormonal links may repeatedly mobilise cardiovascular responses. It also suggests that these responses can be studied in the laboratory as long as experimental tasks provide a stressful challenge (Chida & Hamer 2008; Chida & Steptoe 2010; Turner 1994).
Modern stress research suggests that there are links between stress, psychophysiological inflexibility and many diseases. It is also recognised that there are individual differences in the extent to which individuals are exposed to stress as well as differences in the magnitude of physiological and emotional responses; reactivity to potentially stressful events; speed and extent of recovery and restoration. These individual differences may mediate the relationship between stress and disease (Contrada 2011).

From a psychophysiological perspective, Uchino and colleagues (2007) conceptualised a theoretical framework in an integrative model that includes consideration of physiological, psychological and behavioural dimensions, and focuses on general perceptions of stress rather than attempting to elucidate the precise mechanisms operating to influence health outcomes in different individuals. This model suggests that there are four phases in the stress response – exposure, reactivity, recovery and restoration – and that these processes are central to understanding the mechanism by which stress may contribute to disease (See figure 2.4) (Uchino 2007).

2.4.1 Stress Exposure

Stress exposure refers to the experience of either acute or chronic stress and can be influenced by individual differences. Stress exposure can arise from a
subjective experience, a major life event, daily hassles (such as interpersonal conflict) and cognitive processes (such as anticipation or mentally imagined stress).

**2.4.2 Stress Reactivity**

Stress reactivity refers to individual variations in the immediate physiological or behavioural response to a stressful or potentially stressful event (FlaaAksnes, et al. 2008; FlaaEide, et al. 2008; Moseley & Linden 2006). The frequency and severity of stress exposure can influence stress reactivity (Uchino 2007) through perception of the event (appraisal), subjective distress and physiological arousal (Lazarus & Folkman 1984). Reactivity to psychological stress typically focuses on the magnitude of psychophysiological responses to acute stress with the principal goal of identifying factors and conditions associated with physiological efficiency.

Initially, stress reactivity was hypothesised with a restricted understanding of the role of the SNS in mediating stress response and postulated sympathetic pathways as the potential indicators of the cortical and limbic systems. This rudimentary understanding assuming sudo-motor activities, vascular or cardiac activities as accurate indicators of the SNS was mainly due to their measurement availability. Reactivity theory, through presuming sympathetic innervation in the stress response, originally conceptualised larger physiological reactions (increases in HR, BP and electro-dermal activities) as accurate indicators of sympathetic arousal and potential indicators for the development of cardiovascular pathology (Manuck, Kasprowicz & Muldoon 1990; Obrist 1981). Sympathetically mediated cardiovascular responses to stress may be related to the development of cardiovascular disorders, hypertension and coronary heart diseases.

Recently, this hypothesis has been criticised because it does not take into account the duration of stress exposure and does not include the possibility of slow recovery, prolonged activation, or chronic or repeated stress (Heponiemi et al. 2007). Further research attributed reactivity to SNS activation and neglected the concept of parasympathetic influence. Despite these limitations, the reactivity hypothesis has proven to be influential, durable and consistent with research on acute laboratory stress exposure. Direct evidence in support of the reactivity
hypothesis comes from a number of large-scale cross-sectional and prospective observational studies that describe positive associations between cardiovascular reactions to acute psychological stress and the risk of hypertension (Carroll et al. 2011; Carroll et al. 2003; FlaaEide, et al. 2008; Flaa et al. 2006), insulin resistance (FlaaEide, et al. 2008) and cardiovascular disease (Heponiemi et al. 2007; Kapuku et al. 1999; Lynch et al. 1998).

Extensive reviews of the literature also support for the association between large surges of stress reactivity and pathogenesis. These comprehensive reviews and meta-analysis have reported the relationship between heightened reactivity, sluggish recovery and CVD risk (Chida & Steptoe 2010), high cardiovascular reactivity as a mediator to wide variety of psychosocial and behavioural risk factors, including mood disorientation and hostility (Chida & Hamer 2008) and heightened BP reactivity has been reported as an independent risk factor for hypertension (Treiber et al. 2003).

### 2.4.3 Stress Recovery

Stress recovery refers to the time taken for physiological, psychological and behavioural arousal to return to baseline levels following a stressful event. The parasympathetic nervous system (PNS) plays a central role in recovery; it acts to balance (dampen) the effects of sympathetic activation initiated in the reactivity phase (Uchino 2007; William et al. 2010). Quick recovery from stress-induced arousal reflects effective coping, an efficient self-regulatory activities and flexible psychophysiological system with better cardiovascular health.

Recently, the inability of the cardiovascular system to recover and return to baseline after termination of stress has been asserted as the better predictor of subsequent cardiovascular health (Cacippo & Bernston 2011), while heightened reactivity has been suggested to be adaptive because it may reflect behavioural flexibility, energy mobilisation and effective coping (Porges 2011). These empirical investigations support the position that sluggish cardiovascular recovery associated with psychological stress reflects impaired allostatsis, and may be the dominant marker for the onset of diseases (Moseley & Linden 2006), hypertension (Falkner, Hulman & Kushner 1993; Schuler & O'Brien 1997), atherosclerosis
(Heponiemi et al. 2007), coronary events (Pitsavos et al. 2004) and endothelial dysfunction (Pitsavos et al. 2004). Parallel evidence of faster HR recovery being associated with better health and decreased mortality has been reported in several studies of physical exercise (Lauer & Froelicher 2002). These studies consistently report reactivation of cardiac vagal tone following the termination of the sympathetically activated state of exercise (Thayer & Lane 2007).

Parasympathetic activation, as indicated by high frequency heart rate variability (HRV) or manifestation of respiratory sinus arrhythmia (RSA), is of particular importance to stress recovery. High surges of parasympathetic activities are attributed to an efficient allostatic system (McEwen 2006) that assists in the general inhibitory role of the frontal cortex through the vagus. This is of vital importance to the positive affective states and for preservation of the integrity of the central brain, ANS and periphery (See section 2.9.3) (Thayer et al. 2009).

In contrast, chronic low parasympathetic tone is associated with a low parasympathetic reactivity index, high vulnerability to stress and emotional distress. Porges (1992) suggested that persons with high parasympathetic withdrawal in a challenging situation (capacity to react) and return to baseline (self-regulation) exhibit efficient vagal brake as an appropriate stress response that is suggestive of resilience and psychophysiological flexibility as well as being less susceptible to diseases (See section 10.4) (Porges 1992, 2011).

2.4.4 Stress Restoration

A unique aspect in this perspective is a focus on anabolic processes that refresh or repair an organism. After experiencing stress, restorative processes operate to refresh buttress and repair various from of cellular damage and return an individual to the baseline level of physiological activity (Cacippo & Bernston 2011). Stress exposure, reactivity and recovery may have an effect on restorative process and, in turn, restorative process may influence stress reactivity and recovery.

Within this model, reactivity and recovery have become a focus for researchers and attracted experimental attention because of a hypothesised link
between stress responses and the development of CVD risk factors and cardiovascular events (Cacippo & Bernston 2011). Despite this, the restorative process has had less research focus compared with other aspects of stress response. The efficient restoration of autonomic and physiological responses may have the capacity to restore metabolic and cardiovascular imbalance and reduce disease symptoms, morbidity and mortality. Recent literature suggests that, even a modest reduction in restorative processes (e.g., sleep) is associated with increased susceptibility to illness (Cohen, S et al. 2009) and coronary artery diseases (Kaltsas & Chrousos 2007).

The array of mind–body medicine therapies, including yoga, that facilitate mind–body integration elicit intrinsic anti-stress responses that are mediated through enhanced vagal regulation. This serves to provide the corrective action of restoration in the pre-dominanted sympatho-excitatory physiological system (Taylor, AG et al. 2010). It appears that the coordinated shift towards vagal dominance is a major attribute in the positive affective states and contributes to adaptation to fluctuating situational demands associated with stressors and positively reinforces health and well-being.

2.5 Modelling Stress in Laboratory
(Mental arithmetic stress task)

Altered stress reaction or inflexible behavioural response may signal the presence of disease or an increased risk of disease because the pattern of physiological adjustment to psychological stress is different from that apparent with physical exertion (Carroll, Phillips & Balanos 2009). However, there is a seeming paradox because physiological perturbation to psychological stress leads to pathology whereas broadly similar adjustments during physical exercise are rightly regarded as protective to health and beneficial. The difference may be that the latter is metabolically appropriate whereas the former may not be (Balanos et al. 2010; Obrist 1981).

Several different types of research studies have been performed to provide scientific evidence for the role of psychological stress in wide range of peripheral
diseases. These include acute stress experiments, observational studies and cross-sectional studies that investigated the individual differences in sympathetic drive to identify who may be at risk of cardiovascular diseases. Sympathetic activation to stressful stimuli is not a unidirectional construct; instead, it is highly regional in response to different psychological stressors. Active tasks (mental arithmetic) tend to elicit β-adrenergic (cardiac) activation and increase BP, whereas passive tasks (cold pressure) tend to elicit α-adrenergic (vasomotor) activation and increase BP (Carroll, Phillips & Balanos 2009; FlaaAksnes, et al. 2008).

In research, the mental arithmetic stress task is a venerable stressor with active psychological and cognitive aspects that mimic exposure to the challenges of modern society and day-to-day life events. Measures of cardiac autonomic and metabolic functions can be carried out repeatedly with good test–retest reliability (Chida & Hamer 2008). Despite no standardised procedure, many studies have measured vulnerability with mental arithmetic stress test (MAST) exposure and reported sympatho-excitation with increased oxygen consumption (OC) and HR (Balanos et al. 2010; Carroll, Phillips & Balanos 2009), and a substantial increase in BP (Flaa et al. 2006).

In the paradigm of psychophysiological research of yoga, very small number of studies have explored the effects of yoga practices on reactivity (Hagins, Haden & Daly 2013), whereas the effects of yoga on recovery and restoration process have been yet reported previously.

### 2.6 Stress, Metabolism and Oxygen Consumption (OC)

Human metabolism is the result of continuous anabolic and catabolic processes that maintain homeostasis and sustain life. Metabolic pathways include a complex network of nutritional, neuronal and humoral inputs that are integrated by the central and ANS through pathways that monitor and maintain physiological functioning. All metabolic processes generate heat and are ultimately dependent on the expenditure of energy via consumption of oxygen, which drives oxidative phosphorylation.
Energy expenditure is a directly related to metabolic rate and OC and these terms are often used interchangeably. Monitoring OC has received a great deal of interest in determining oxygen delivery to tissues, cardiorespiratory function and metabolic response to activity. Assessment of OC is used in determining energy requirements for healthy lifestyles, exercise programs, and critically ill patients and oxygen consumption is reported to increase with adaption to physiological stress and pathology.

The measurement of OC can provide insight into overall homeostatic balance and response to stress which are mediated through multiple pathways under the control of the ANS and hypothalamus. The SNS is involved in rapidly mobilizing vital physiological functions via SAM pathways in response to acute stress which serves to increase OC. While in contrast the PNS provides a counter to the stress response and reduces OC which serves to reduce physiological arousal and induce hypometabolic state mediated via enhanced vagal activity. Such activities are suggested to facilitate restorative function.

The association between stress, OC and yoga are reported in chapter 6: *Oxygen consumption changes with yoga practices: A systematic review*

### 2.7 Stress, Autonomic Control and Heart Rate Variability (HRV)

The HR in healthy human is not steady as it is influenced by physical, emotional and cognitive activities and physiological oscillations that to lead to variable beat-to-beat fluctuations in HR known as HRV. HR and HRV are perhaps the most sensitive and easily accessible indicators of autonomic regulation and vagal activity. A high resting HR is a known risk factor for cardiac disease, while a lower resting HR reflects efficient vagal activity and flexible autonomic regulation. HRV reflects the dynamic balance arising from the co-activation, co-inhibition or reciprocal activation or inhibition of the sympathetic and PNS and therefore HRV also provides a proxy for the health, adaptability, flexibility and neural regulation of the cardiovascular system.

There is growing evidence that physiological and psychological stress disrupts autonomic balance and that prolonged autonomic imbalance is associated
Chapter 2
Stress and Mind-Body Balance

with a wide range of somatic and mental diseases that are characterised by dominant sympathetic and inhibited parasympathetic activity. Such autonomic imbalance is reflected in measures of HRV, which have been positively associated with fitness, resilience, psychological and physiological flexibility and negatively associated with cardiovascular disease, stress and negative affective states characterised by autonomic inflexibility and maladaptive stress responses.

Further, the association between stress, HRV and yoga are reported in chapter 7: Yoga and Heart Rate Variability (HRV): A systematic review:

2.8 Non-Invasive Psychophysiological Measures of Stress

The organism is a collection of dynamic, adaptive, interactive and interdependent physiological systems and often this state is called the harmonious or coherent state. The peripheral organs are anchored to the CNS and ANS through efferent (transmitting information from central structure to body) and afferent (transmitting information from body to central structures) pathways. The first physiological axis to become activated during stress exposure is the ANS, which regulates the activities of the cardiovascular, respiratory and metabolic systems as well as being independently subjected to psychological and behavioural variation.

The inherent critical relationship between stress, health and disease is determined either by measuring, recoding or otherwise quantifying key variables. In recent years, there has been a great shift towards biological measures using advanced recording equipment techniques that are non-invasive and give more precise and accurate physiological measures, both under laboratory conditions and in the natural environment. These non-invasive peripheral measurement methods linking the mind and body not only reflect the autonomic status but are also a window to limbic and cortical activities.

The most obvious configuration (which dominated physiology for decades) is on in which SNS dominates. In voluminous stress research studies, the investigators were searching for a ‘sticky accelerator while overlooking bad breaks’ (Thayer & Friedman 2002). However, not acknowledging the influential
role of visceral afferents in regulating the stress response has restricted the understanding of several important factors: parasympathetic influence; interaction between sympathetic and parasympathetic processes; the adaptive dynamic and flexible nature of the ANS— and autonomic flexibility (See section 2.10); and central regulatory structure (See section 2.9.3).

With the upsurge in research that has used non-invasive HRV analysis as a window into cardiac vagal control, the results were reversed. The advent of HRV with broad theoretical and clinical implications for adaptive functions in changing environment acknowledged two notions: reconsideration of the understanding of classical homeostatic process, allostasis; and the important role of inhibition in self-regulation (Thayer et al. 2009). Further, two metrics, the HRV as the index of parasympathetic cardiac activity, and OC as the index of sympathetic activity (β-adrenergic activity), may provide information on the status of autonomic regulation in varied population and appear have to clinical relevance in multiple stress-related diseases, such as cardiovascular, metabolic syndrome and hypertension.

The measurement of oxygen consumption can provide insights into overall homeostatic balance and response to stress, which are mediated through multiple pathways under the control of the ANS and the hypothalamus. The SNS is involved in rapidly mobilising vital physiological functions via SAM pathways in response to acute stress (Lambert & Lambert 2011; Licht et al. 2010; Vaccarino & Bremner 2005) which serves to increase oxygen consumption. Repeated or chronic stressful stimuli may lead to changes in the HPA axis leading to a sustained stress response involving cognitive, emotional, endocrine and immune system changes (Kyrou & Tsigos 2009). The PNS provides a counter to the stress response and reduces oxygen consumption by activating the so-called ‘relaxation response’ (Benson 1975), which serves to reduce physiological arousal and induce a hypometabolic state mediated via enhanced vagal activity (Dusek & Benson 2009). Such hypometabolic states are suggested to enhance survival in plants and animals by facilitating restorative and repair functions (Storey & Storey 1990).
2.8.1 Measurements of Oxygen Consumption

The measurement of energy expenditure can be performed via direct calorimetry, which measures heat loss using insulated chambers, or via indirect calorimetry, which directly measures oxygen consumption (Levine 2005) through respiratory gas exchange. Direct calorimetry is not frequently used as it is complex, does not accurately measure rapid changes in metabolism and requires significant expertise and elaborate equipment including specially constructed chambers. Indirect calorimetry, is the most commonly technique for measuring energy expenditure and can be used to measure the substrate of metabolism as well as oxygen consumption, which can be expressed in terms of VO₂ (Absolute oxygen consumption), VO₂/min/kg (Relative oxygen consumption), and MET (Metabolic Equivalent Task) (Bonnet & Arand 2003; Glass, Dwyer & American College of Sports 2007; McArdle, Katch & Katch 2010).

2.8.1.1 Measuring Oxygen Consumption through Dilution Technique

There are two approaches to metabolic monitoring through indirect calorimetry. In the closed-circuit method, the subject breathes from an O₂ reservoir, and through the change in volume, the VO₂ is calculated. This method is cumbersome and the accuracy has been questioned due to higher RMR (5–10%) values compared with the open-circuit method. (Clark & Hoffer 1991). In the open-circuit method, the subject breathes normally and expires into a gas sampling system. The gas collection system may vary between breaths or by dilution technique.

In the dilution technique, using a ventilatory hood (canopy) with no air leakage allows for accurate oxygen consumption measurements in clinical and laboratory settings. The ventilatory hood technique appears to be the most comfortable technique because of the ability to breathe more naturally than with a mask or mouth piece (Owen et al. 1986; Scott 1993). The results from the study also find a higher metabolic rate obtained using a mouth piece or mask compared with a canopy (Compher et al. 2006; Roffey, Byrne & Hills 2006).
2.8.1.2 Standard Conditions for Oxygen Consumption Measurement

For measuring energy expenditure using indirect calorimetry, American Dietetic Association has recommended certain dimensions for the accuracy of the oxygen consumption and metabolic rate (ADA 2003). Following are the areas associate that needs adherence while measuring resting oxygen consumption (Compher et al. 2006):

- Machine calibration;
- Minimum of 5 hours fasting period after meals or snacks;
- Minimum of 2 hours abstain from nicotine and 4 hours for caffeine before oxygen consumption measurement;
- A minimum of 10 – 20 minutes resting period prior to measurement;
- A minimum of 2 hours abstention from moderate aerobic or anaerobic exercise and 14 hours for vigorous exercises;
- Physically comfortable position for measurement during test;
- Laboratory temperature between 20°C to 25°C;
- Rigorous adherence to prevent leakage in gas collection;
- Discarding initial 5 minutes of VO2 sample to attain steady state;

2.8.2 Measurement of Quantification of HRV

HRV is generally measured using the R-R interval (QRS peak) on an electrocardiogram and a variety of measures have been used to operationalize HRV. The beat-to-beat fluctuation in instantaneous HR reflects the chaotic properties of the heart and provides a strong indicator of adaptability, and resilience. The R-R interval is generally measured in either the time or frequency domain. At rest with the time domain reflects respiratory sinus arrhythmia, which is mediated by parasympathetic cardio-vagal outflow (Acharya, R. U. 2007; Task Force 1996).

Further, quantification and measurement of Frequency domain analysis has been reported in chapter 7 Yoga and Heart Rate Variability (HRV): A systematic review:
2.8.3 Psychological Measures

Psychometric measures are efficient and relatively quick for assessing health, behaviour, emotions and stress in psycho-physiological research and clinical settings. These self-rated psychological states are measured through a set of questionnaires, and are potentially validated predictors of morbidity and mortality, and can be a proxy for several extensive physiological measurements (Benyamini 2011). Psychological measures can be understood as:

...a summary statement about the way in which numerous aspect of health or behaviour, both subjective and objective are combined with in the perceptual framework of the individual respondent (Tissue 1972, Pg. 93).

Studies suggest that self-rated assessment involves conscious reasoning, appraisal, subjective perception, experience and cognitive functioning of the respondent embedded in a social and cultural environment (Jylhä 2009). These measures indirectly represent emotional and behavioural constructs through self-judgement, as well as providing accurate information about changes over time that are the cornerstone in the realm of mind–body construct.

2.8.3.1 Profile of Mood States

The Profile of Mood States (POMS) is a factor-analytically derived self-administered instrument to assess mood state in a wide range of population that provides 6 identifiable mood and affective states on 5 point scale ranging from ‘not at all’ to ‘extremely’. For calculating total mood mood disturbance (TMD), the 5 mood states (1) Tension/anxiety ‘T’, (2) depression/dejection ‘D’, (3) anger/hostile ‘A”, (4) fatigue/inertia ‘F’, and (6) confusion/bewilderment ‘C’ are added (T+D+A+F+C) and sixth (6) vigor/activity ‘V’ is subtracted from the sum.

The POMS offers a broader range of state measures for the subjective assessment of stress when compared with the State Trait Anxiety Inventory ‘STAI’, Subjective Stress Scale ‘SSS’ and Affect Adjective Check List ‘AAC: and Multiple Affective Adjective Check List ‘MAACL’ (Everly & Lating 2012).
2.8.3.2 Flow Scale

The flow scale facilitates the examination of the flow experience in the construct of variety of life domains such as performance at sports, music, work and school performance as well as day to day life task. The scale quantifies the optimal positive psychological experience when the individual is finely balanced with the capacity and the challenges (Jackson 2012).

The flow scale represent nine dimensions of the peak positive experience and measure it through, Flow state scale (FSS) which quantifies ‘flow as a state measure’ and the Dispositional Flow State (DFS), which quantifies ‘flow as a trait’ The nine established dimension of flow are: (1) challenge skill balance; (2) action-awareness merging; (3) clear goal; (4) unambiguous feedback; (5) concentration on the task at hand; (6) sense of control; (7) loss of self-consciousness; (8) time transformation; (9) autotelic experience

2.9 Stress Regulatory System

Stressors can affect the brain and the body of an organism by inducing biological changes, and the stress system can be observed as multiple linkages between the large neuronal and humeral network of the central, peripheral, endocrine and immune systems (See figure 2.9 (a); Appendix 1) (Cacioppo 2007). The membranes of the cells in these systems have receptors that react to information transmitted from the other two systems. The brain is the master regulator of the neuro-endocrine, autonomic and immune systems as well as behaviours and emotions that contribute to health and ill-health, and in turn, influence the physiological process of allostasis (McEwen 1998b, 2006). The stress regulatory system is superbly designed with an inhibitory system for effective functioning in complex environments and the stress response efficiently reacts to acute stimuli across a range of severities and is able to recover after each stimulus so that the organism is ready to respond to a new stimulus (Darwin 1999/1872; Porges 2011).

Physical and psychological or emotional stressors activate the stress system network through separate but convergent biological pathways that influence the
peripheral organs. Although different types of stress are involved, the end is mediated through peripheral pathways of the stress system network. Unlike physical stress— which is a reaction to an actual disturbance to homeostasis—psychological or emotional stressors can elicit a stress response in anticipation of a potential homeostatic disturbance and without a primary stress stimulus. The role of psychological stressors in the development of physiological complaints and the wide variety of stress-related diseases is well documented (Steptoe & Kivimaki 2013).

The stress system network, with its highly connected conserved brain structures, peripheral limbs and feedback circuits, regulates metabolic demand in response to changing environmental conditions. The activation of the stress system network exerts a profound modulatory effect on energy mobilisation and causes the redistribution of oxygen to active organs and tissues. The stress regulatory network receives and integrates diverse cognitive, emotional, neurosensory and peripheral signals that arrive through distinct pathways. The key biological pathways through which the stress system network influences the periphery include: the sympathetic branch of ANS (SNS) including SAM system; the parasympathetic branch of ANS; and the HPA system (Kaltsas & Chrousos 2007; McEwen 2006).

With the advent of brain imaging methods in humans, it is becoming apparent that, with multiple sites of interactions, the entire brain is involved in responding to the psychological or emotional state and, therefore, influences the peripheral system. Researchers have generally focused on activation of the SNS and have identified the functional units in the central nervous system. One such entity is the central autonomic network (CAN) which is critical for goal-directed behaviour, adaptability, flexibility and health (Beissner et al. 2013; Kaltsas & Chrousos 2007). The structural components of the CAN are found at the level of the forebrain, midbrain and hindbrain. Functionally, the CAN is capable of producing widespread effect on autonomic, neuroendocrine and behavioural responses and can activate the SNS, SAM and HPA axis pathways and vagal complex to a variety of new stimuli (See figure 2.9 (b); Appendix 2) (Cacippo & Bernston 2011; Thayer & Friedman 2002).
The description of stress regulatory system is beyond the scope of this research and has been explained elsewhere (Cacippo & Bernston 2011; Kaltsas & Chrousos 2007). However the following subsections provide a succinct view to understand the mechanisms through which stress triggers the responses that splits mind and body resulting in to myriads of disease conditions while yoga practices stimulate the responses that integrates mind and body and generates a coherent state called the ‘yogic state’.

### 2.9.1 Sympathetic Nervous System (SNS)

The prudential catabolic pattern of SNS responds to external challenges to inhibit vegetative functions and assist in stress arousal by promoting metabolic functions that quickly mobilise bodily reserves to optimise the relationship with the environment. Sympathetic activation is highly specific and, because of differences in the receptors of the arterial walls, catecholamine causes vasodilation within internal organs through α-adrenergic receptors and causes vasoconstrictions in the periphery through β-adrenergic receptors in cutaneous tissues (Cacippo & Bernston 2011). This pattern of physiological adjustment with adaptive characteristics protecting the organism demonstrates the efficiency of self-regulatory activities. Whereas the long-term adjustments associated with chronic psychological stress are maladaptive and reflect a hyper-sympathetic state leading to a lack of dynamic flexibility that results in stress-related diseases, such as cardiovascular diseases and features of metabolic syndrome including hypertension.

### 2.9.2 Parasympathetic Nervous System (PNS)

PNS dealing in anabolic activities promotes vegetative and restorative functions that are primarily associated with conservation of energy and resting of vital organs, such as HR. This view was clearly stated by Cannon (1929a):

> A glance at these various functions of the cranial division reveals at once that they serve for bodily conservation; by narrowing the pupil they shield the retina from excessive light; by slowing the heart rate they give the cardiac muscle longer periods for rest and invigoration; and by providing for the flow of saliva and gastric juice, and by supplying the necessary muscular tone or the contraction of the
alimentary canal, they prove fundamentally essential to the processes of proper
digestion and absorption by which energy-yielding material is taken into the body
and stored. To the cranial division belongs the great service of building up reserves
and fortifying the body against time of need and stress (Cannon 1929a, pg. 31-32).

The recent stress model explains that the phylogenetically arranged PNS has
functionally distinct two vagal systems that in opposition to the SAM system are
actively involved in mobilizing behavioural responses. The integrated vagal
complex fosters two roles: visceral homeostasis -promotes restoration and
growth, and motor response relate physiological responses to meet environmental
demands and reflects fight and flight behaviour (Thayer & Sternberg 2006).

In this regard, the polyvagal theory specifying the vagal complex provides
the justification for ‘vagal brake’. The theory proposes that successful adaptation
of the organism is dependent on systematic and reliable withdrawal and re-
engagement of the vagal brake as a mechanism to rapidly regulate sympathetic
activities in response to environmental challenges. The theory suggests that the
vagal system deals with both serving the needs of internal viscera and with
responding to external challenges (Porges 2011). The Ability of efficient trade-off
determines adaptive behavioural and homeostatic regulation indicating autonomic
flexibility (Thayer & Sternberg 2006). While, in contrast with excessive stress,
withdrawal of vagal break functionally degrades and has detrimental effects
leading to psychophysiological inflexibility and allostatic load that serves to
physical and mental diseases (Porges 1992; Thayer & Lane 2000).

2.9.3 Neurovisceral Integration:
Central Peripheral Interactions and Importance of Inhibition

Researchers have been consistently proposing that measure of cardiac vagal is a
vital aspect of self-regulation and it serves to quantify the ability of the system to
modulate physiological resources and generate appropriate responses through
neural feedback mechanism of CNS and ANS (Thayer & Lane 2000). Thus cardiac
vagal tone reflects CNS-ANS integration and its influence on periphery (See figure 2.9.3). The Neurovisceral integration model suggested by Thayer and colleagues includes specific components of CNS–ANS controlling visceraomotor, neuroendocrine, goal-directed behavioural and adaptability. The authors suggested that the CAN is one such functional and structural network of CNS that exerts inhibitory control over sympathetic activities. The structural components of CAN exert inhibition via frontal cortex activities and functionally the inhibition is mediated via GABA-ergic neurons, the main inhibitory neurotransmitters within the CNS that inhibit sympatho- excitatory circuits within CAN (Thayer & Sternberg 2006). The disruption of this inhibitory pathway may lead to severe stress and sinus tachycardia resulting in attenuate RSA or low HRV.
2.10 Influential Role of (In)Flexibility: Autonomic and Psychological

Flexibility has been the vital construct in psychology and physiological domains and each has provided the specific explanations and have highlighted that flexibility is reduced in many forms of stress related pathological conditions (Kashdan & Rottenberg 2010). However it is less clear whether this inflexibility is a antecedent or a consequence of pathology, an issue that connects causal status of inflexibility as marker of health. The pervasive and widespread nature of evidence for inflexibility in so many different response systems and in so many stress related disorders is overwhelming (Kashdan & Rottenberg 2010; Thayer & Lane 2000). To reduce these widespread construct of inflexibility researches have focused only on a smaller core set. The promising lead that explains and integrates the various manifestation of inflexibility is cardiac vagal tone. Higher vagal tone is suggestive index of self-regulation and behavioural flexibility (Kok & Fredrickson 2010).

Besides understanding the concept of autonomic flexibility and cost of inflexibility and associated allostatic load, it is important to focus on autonomic regulations that involve the construct of autonomic balance and autonomic flexibility. The concept of autonomic balance focuses on homeostatic reflexes (when the visceral organs are innervated by SNS and PNS antagonistically) and involves lower level of autonomic regulation. However, the extended work of allostasis that explains unique situations that may initiate the autonomic responses (McEwen 2006) which are characterised either by dual innervation or dual inhibition hence suggesting that there are likely to be difference in autonomic balance and autonomic flexibility (Porges 2011). This indicates the body is a unified entity and is involved in an attempt to produce a contextual appropriate response to challenges. Similarly the whole brain is also involved in generating responses (Thayer & Lane 2009).

Relatively recent the research suggests that individuals differ enormously in their responses to challenges (Erikson & Urisin 2006). Stress responses are mediated via top down mechanism. This together with the evidence suggesting
the important role of vagus in health and diseases reinforces the construct that autonomic regulations are not autonomic balance perse but are the dimensions of flexibility. On the other hand, extensive literature in the continuum of flexibility codifies psychological flexibility to autonomic flexibility that includes interactions between amygdala, prefrontal cortex and peripheral interactions via autonomic activities and justifies plausible reasons for the implications of cardiac vagal tone as an index to flexibility (Kashdan & Rottenberg 2010).

First, it is biologically plausible and reflects the integration of cognitive and emotional processes in cortical and subcortical brain areas and the goal is to facilitate adjustment to the changing environment. Secondly cardiac vagal tone has functional relationship to the body. The vagus innervates a number of end-organs that are involved in emotion and communication (for example; larynx, facial muscle, (Porges 2011), and vagal function as brake allowing rapid mobilization of the body to meet a variety of environmental and metabolic demands these include physical exercise, coping, stress appraisals.

### 2.11 Allostatic Load- Stress and Pathophysiology

Allostasis has a price (See Figure 2.11). The chronically elevated allostatic system is characterised by a higher set point with diminished ability to terminate the activated HPA axis and SAM pathways. This sympathetically predominated system with unimpeded energy mobilization down regulates the negative feedback mechanisms that under normal conditions apply break on the system. Alternately the incapability of the stress response system to shut off, results in compromised adaptation and physiological system is unable to switch to process of repair and restorative activities (Kaltsas & Chrousos 2007; Porges 2011) This psychophysiological inflexibility results in cumulative wear and tear of the system reflecting allostatic load and contributes to end-organ dysfunction, such as features of metabolic syndrome and cardiovascular diseases (McEwen 1998b, 2006).

Further the speculations have been made that if interventions to reduce allostasis occur early enough, the effects of allostatic load are reversible and that may promote proper functioning of inhibitory processes. The promising construct
of mind-body medicine therapies with goal directed behavioural modulations integrate psychophysiological system that develops the ability to self-regulate the resource that inhibits sympathetic activities and facilitate the efficient vagal control.

Central Role of Brain Allostasis (Figure)

CHAPTER 3
Stress and Diseases

3.1 Introduction

This chapter providing the description of physiological diseases such as cardiovascular diseases (CVD) and metabolic syndrome (MetS), addresses the burden of diseases and lays the foundation for the cost-effective, non-invasive and safe yogic intervention.

The cardiovascular system that serves to maintain the supply of oxygen and other nutrients to, and the removal of waste products from, all the cells in the body is of the central focus in physiological investigation for several reasons. First, at least some of its parameters (such as HR and BP) are readily observed. Second, the cardiovascular system is highly sensitive to neurobehavioral processes because it is extremely complex and includes multiple regulatory subsystems that are subject to central and peripheral autonomic controls and humeral influences. Finally, the complexity of the cardiovascular system renders it susceptible to a variety of disorders and pathogenesis, which makes CVD responsible for the largest health care burden.

The specific aims of this chapter are threefold: (1) exploring the dynamics of stress and the role of chronic stress that influence peripheral end organs and emerge as cardiovascular risk factors; (2) to extend the understanding of the physiological mechanism of MetS, which with its roots in stress serves as the leading cause of CVD and economic burden of these diseases (3) to examine the suggestive and prevailing treatment approaches by health care agencies and will lastly discuss the therapeutic importance of mind-body medicine including yoga for the treatment and intervention of MetS. This will lay the ground for the further chapter that will provide the historical and philosophical background of yoga and will investigate the current available literature on yoga and psychophysiology that further will lead to the investigation portion of this thesis.
3.2 Dynamics of Stress
Cardiovascular Diseases (CVD) and Metabolic Syndrome (MetS)

3.2.1 Cardiovascular Diseases

CVD is a broad term that includes all diseases and conditions of the heart and blood vessels, and is responsible for 33% of all deaths globally (WHO 2013b). The individuals predisposed to CVD have shorter life expectancy, lower quality of life and higher health care cost (Steptoe & Kivimaki 2013). It is expected that by 2030, worldwide more than 28 million people will die each year from cardiovascular disease (WHO 2013b).

A considerable body of literature shows that chronic stress, both in early life and during adulthood, influences the development of stress-oriented diseases across the life course and also affects risk factors for future CVDs (Steptoe & Kivimaki 2013). Understanding the biological mechanism linking stress to CVD at a population level remains an ongoing challenge. However, several studies have linked stress to clustering features of MetS, CVD and diabetes mellitus II (DM-II) (Chandola, Brunner & Marmot 2006; Steptoe & Kivimaki 2013). A very recent meta-analysis found that the risk of coronary heart disease increased 1.5-fold among adults experiencing social isolation and 1.3-fold for adults experiencing workplace stress, with adverse metabolic changes being the plausible mechanism. This review further suggested that anger and mood were the plausible factors acting as acute triggers of major cardiac events (Steptoe & Kivimaki 2013).

It has also been suggested that most CVD could be prevented by addressing modifiable risk factors such as obesity, high BP, diabetes/raised glycaemic index, raised lipid profile and sedentary lifestyle (Thayer & Lane 2007; WHO 2013b). Furthermore there is a relatively large body of literature linking CVDs to MetS, which itself has been largely associated with stress.
3.2.2 Metabolic Syndrome

MetS affecting 25-30% of the world’s adult population (AHA 2012) is largely attributed to lifestyle and maladaptive dietary habits with major health care burden and a driving force to CVD (WHO 2011). With continuous dramatic increase in the prevalence of MetS has resulted in the number of individuals diagnosed with DM-II worldwide being expected to surpass 360 million by 2030 (WHO 2011). The features of MetS include such central obesity, hypertension, hyperglycaemia, elevated triglycerides and low level of high-density lipoprotein cholesterol and their tendency to manifest concurrently has placed a greater emphasis on understanding, diagnosing and effectively managing them as a unified syndrome. At the core of this pathophysiology is the gradual and progressive distortion of normal metabolic homeostasis that affects all of the major metabolically active organs and tissues.

The promising stress research on MetS reports, that there is a 2-fold increased risk for CVD and a 5-fold increased risk for DM-II (IDF 2005). The clinical utility of diagnosing MetS in general practice has been hampered by the inconsistency of the diagnostic criteria, with several different definitions of the term being used in the medical literature (Kahn et al. 2005). Despite uniform pathology, the exact definition of MetS is not fully agreed upon (Kassi et al. 2011). The criteria for the definition of MetS vary among various global regulatory authorities, making it difficult to have consistent diagnoses (Wang, M 2011). The dichotomous variables and diagnostic criteria or cut off points all vary between expert panels such as World Health Organisation (WHO), European Group for the Study of Insulin Resistance (EGSIR), National Cholesterol Education Program Adult Treatment Panel III (NCEP-ATPIII), American Association of Clinical Endocrinology (AACE), American Heart Association/National Heart Lung, and Blood Institute (AHA/NHLBI), International Diabetic Federation (IDF). However, the common features are the same (See Table 3.2.2; Appendix 3).

To identify patients with MetS, in 2005, the International Diabetes Federation (IDF) endorsed a simple diagnostic set of criteria with different parameters incorporating the core components previously acknowledged by major
expert panels and international organisations, including the World Health Organization (WHO), National Cholesterol Education Program’s Adult Treatment Panel III, European Group of Insulin Resistance, American Association of Clinical Endocrinologists and the American Heart Association and National Heart, Lung and Blood Institute (Alberti, Zimmet & Shaw 2006; ATPIII 2001; Balkau & Charles 1999; Einhorn et al. 2003; Grundy et al. 2004; IDF 2005). The new diagnostic tool introduced abdominal obesity, with special emphasis on waist circumference or body mass index \( \geq 30 \), as a prerequisite for the syndrome and the presence of two of the four other criteria: raised BP, raised triglycerides, reduced high-density lipoprotein cholesterol, raised plasma glucose or diagnosed diabetic mellitus II (IDF 2005).

MetS is well known for exacerbated aging, altered emotional behaviour, negative mood and mitochondrial inflexibility (Nolan 2013; Wang, M 2011). Other abnormalities associated with MetS are linked to pathogenesis and progression of chronic diseases and include hyper-coagulation, chronic inflammation, endothelial dysfunction, oxidative stress and reduced bioavailability of insulin-like growth factor (Joel 2011). Cancer, gout, non-alcoholic fatty liver diseases, polycystic ovary syndrome, sleep apnoea and dementia may also result from the development of the syndrome (Wang, M 2011). The prevention and treatment of MetS is currently the focus of intense research activity because of its continuous and consistent alarming increase in prevalence.

3.2.2.1 Evidence Linking Metabolic Syndrome to Cardiovascular Diseases

The individual components of MetS represent pre-nosologic or prodromal states for subsequent diseases states. Hypertension and dyslipidaemia lead to CVD, while obesity and hyperinsulinemia lead to DM-II and also predict increased CVD risk. The pathophysiological mechanism by which, MetS increases the risk for cardiovascular remains unclear and is the subject of debate. However, the association between MetS and the risk of CVD morbidity and mortality have been examined in 5 published meta-analyses that strongly link the syndrome to CVD
events (Galassi, Reynolds & He 2006; Gami et al. 2007; Hu et al. 2004; Mottillo et al. 2010; Wu, SH, Liu & Ho 2010).

These meta-analyses concluded higher risk of CVDs and all cause of mortality in people with MetS compared to the people without MetS (Hu et al. 2004; Mottillo et al. 2010; Wu, SH, Liu & Ho 2010) and this association was stronger in women compared to men (Galassi, Reynolds & He 2006; Gami et al. 2007). Thus the investigators made strong recommendations for the treatment approaches that may successfully reduce the global burden of CVD diseases.

### 3.2.2.2 Evidence Linking Stress to Metabolic Syndrome

The notion that stress leads to MetS and CVD risk factors is entrenched in the scientific evidence (Alberti et al. 2009; Grundy et al. 2005). This relationship has consistently been reported in several longitudinal medical studies that found that exposure to chronic stress such as work, home, socioeconomic status, major or negative life events leads to multifaceted MetS (Block et al. 2009; Brunner et al. 1997; Chandola, Brunner & Marmot 2006; Fowler-Brown et al. 2009; Pyykkonen et al. 2010; Räikkönen, Matthews & Kuller 2007; van Jaarsveld et al. 2009; Vitaliano et al. 2002; Vogelzangs et al. 2007) in both adults and adolescents. These metabolic abnormalities have largely been proposed to be the result of sustained overdrive of sympathetic activities that elicit neuroendocrine effects, noradrenaline, activation of adreno-medullary, and adrenocortical or autonomic dysfunctions associated with stress (Alberti, Zimmet & Shaw 2006; Chandola, Brunner & Marmot 2006; Lambert & Lambert 2011).

### 3.2.3 Potential Physiological Mechanism of Metabolic Syndrome

Although, decades of research effort have been devoted to understanding the aetiology of MetS, there is no single causal mechanism that can explain the constellation of risk factors for MetS. There are several potential biological and mechanistic views that may explain the development of MetS (Nolan 2013; Steptoe & Kivimaki 2013; Wang, M 2011). Obesity and insulin resistance are believed to be the central components, but there is no concrete mechanistic evidence to support this notion (Nolan 2013; Wang, Z et al. 2006). Mechanistic
studies also provide compelling evidence for the association between hypertension and insulin resistance, which is the prime attribute in developing DM-II and later complications of diabetes especially CVD, chronic kidney disease, retinopathy and neuropathy (Wang, M 2011).

More recently, the field of metabolomics has emerged to explain the biological basis of MetS with a completely new profile-metabolic inflexibility. This approach proposes that impaired mitochondrial oxidative phosphorylation is the driving factor of metabolic inflexibility further leading to features of MetS.

3.2.3.1 Metabolic Flexibility and Mitochondrial Efficiency

Metabolic flexibility is the capacity of the organism to adapt to fuel oxidation to fuel availability (Nolan 2013, Pg 28).

Skeletal muscle glucose and lipid oxidation are largely determined by the quantity and function of mitochondria that contributes to metabolic flexibility. Contribution of skeletal muscles in the pathology of MetS is comprehensive, due to the fact that, they are responsible for 40-50% of the body mass, 25-35% of resting oxygen consumption and with abundant insulin sensitive tissues handle 75% to 95% of all insulin mediated glucose disposal (Stump et al. 2006). The metabolically healthy skeletal muscle are characterised by ability to switch easily between glucose and fat oxidation in response to homeostatic signals. The term *metabolic flexibility* was coined by Kelly and Mandarino (2000) as:

> the capacity to switch from predominantly lipid oxidation and high rates of fatty acid uptake during fasting conditions to the suppression of lipid oxidation and increased glucose uptake, oxidation and storage under insulin stimulated conditions (Kelley & Mandarino 2000, Pg 681).

Consistent with this description, metabolic flexibility has two facets: insulin suppresses fat oxidation and stimulates glucose oxidation, while fasting stimulates reliance on fat oxidation. The ability to adjust and increase lipid oxidation in response to increased availability reduces the formation of harmful lipid products and thus protects against changes in insulin sensitivity. An important corollary to this is that lifestyle with caloric restrictions and behavioural interventions may
have the potential to affect mitochondrial dysfunction and restore or improve metabolic flexibility in skeletal muscles, thereby contributing to efficient lipid oxidation, improve insulin action and increase nitric oxide generation autonomic terminals (Dusek et al. 2008; Nolan 2013).

In contrast, maladaptive behavioural lifestyle and unhealthy nutrient intake deregulate the cellular efficiency to modify fuel oxidation in response to nutrient availability for oxidation resulting in accumulation of intramyocellular lipid insulin resistance and reactive oxygen species (ROS) (Wang, M 2011). Further chronic accumulation of lipids impairs insulin action through a variety of mechanisms. Reduced functional capacity of insulin action inhibits nitric oxide (a short lived nitrogen free radical) production and has a prominent role in vasoconstriction, baroreflex dysfunctions resulting in elevated BP and a myriad of other actions leading to disrupted cardiovascular homeostasis (Dusek et al. 2008; Wang, M 2011).

3.3 Economic Burden of Diseases

There are clear consensus that the increasing prevalence of MetS has an enormous impact on medical costs associated with the related health outcomes such as DM-II and CVD (Marangos, Okamoto & Caro 2010). CVDs is the leading cause of death and responsible for more than 2,150 deaths each day (nearly 1 death every 40 seconds) (Go et al. 2013). In 2009, these diseases accounted for 15% of the total US health expenditure resulting in a total estimated cost of $394 billion to the US economy (Go et al. 2013).

It has been reported that the patients with CVD and diabetes incur two fold higher use of hospital and health resource than the individuals without diabetes or individuals without CVD risk factor (Yang, W, Dall & Halder 2013). Further an individuals with clinical profile of MetS needs higher inpatient , outpatient and primary care that require about $2000 greater health care expenditure annually compared to non-MetS individual (Boudreau et al. 2009).

In the US, strong evidence of the economic burden of MetS comes from Medicare claims data and large nationally-representative datasets providing the
information that each additional component of MetS increases the medical cost (Marangos, Okamoto & Caro 2010). In this sequence Curtis and colleagues (2007) have reported that MetS patients with more inpatient stay, greater number of primary care visit resulted in 20% higher Medicare cost. The results also reported that each individual component such as waist circumference, lipids profile and elevated BP were significant predictor of 15%, 16% and 20% greater medical cost respectively (Curtis et al. 2007). Similarly, Nicole and Moler (2011) reported that each individual component of MetS elevated the medical cost that ranged from $423 for impaired glucose to $ 888 for hypertension. The study further reported that annualised medical cost significantly increased to $1,611 with development of diabetes (Nichols & Moler 2011).

3.4 Prognosis and Treatment Approaches for Metabolic Syndrome

The compelling goal of the treatment of MetS is to delay the progression of metabolic deterioration. The treatment recommendations addressing the underlying features of MetS primarily focused to insulin sensitivity and reduce sympathetic activities (Eckel et al. 2013). The global authorities acknowledge, and are in favour of, such therapeutic interventions that may initially targets multiple risk factors simultaneously (Alberti, Zimmet & Shaw 2006; Chobanian et al. 2003; IDF 2005). Food and Drug Administration (FDA) 2007, USA stated that:

a therapeutic product intended to treat metabolic syndrome should normalise all components of the syndrome, independent of weight loss and ultimately be shown to prevent the development of type 2 diabetes and reduce CV morbidity and mortality (FDA 2007).

It has been strongly suggested that, not all patients diagnosed with MetS require medication, but lifestyle modifications (adhering to heart healthy diet, maintenance of healthy weight and increased physical activity) are highly recommended and are of great clinical importance, both prior and in concert with drug therapy (Stone et al. 2013).
3.4.1 Pharmacological Management and Metabolic Syndrome

The choice of drug treatment for MetS is controversial, and there is no approved drug that can reliably reduce all the metabolic risk factor over the longer term (Matfin 2010). Generally the prescribed drugs focus to ensure the lowering risk of CVDs and include conditions such as antidiabetic, antihypertensive, lipid lowering, antiplatelet, statins, angiotensin converting enzyme inhibitor, angiotensin II receptor blocker and thiazolidinedione (Grundy 2006; WHO 2013a).

Presently, there are two potential suggestive approaches of drug therapy for MetS and both have strong weakness. The first, single risk factor approach proposes to identify and treat each factor separately (Matfin 2010). This eventually leads to the problems of polypharmacy with progression of diseases, that contributes to possibility of untoward effects (drug side effects, drug–drug interactions, failure of adherence and medication errors) and simultaneously increases the cost of therapy (Grundy 2006).

While the second approach suggests multifunctional drugs, a poly-pill or single capsule containing a combination of drugs addressing various components of MetS simultaneously such as combining aspirin, a β-blocker, an angiotensin converting enzyme inhibitor, a statin, a diuretic and folic acid (Matfin 2010) all in one tablet. This treatment method may result in improved compliance and decreased cost with a greater impact on complications (Grundy 2009). Nonetheless, the possible drawbacks of the use of a poly-pill include difficulties in initiating and titrating treatment as well as exposing the patient to medications that they may not need (Grundy 2009). Further, if a patient experiences an adverse event, it could prove difficult to determine which component was the cause (Grundy 2009; Matfin 2010).

3.4.2 Lifestyle Treatment and Metabolic Syndrome

Behavioural modifications, physical exercise and dietary patterns have salubrious effects and the intervention of these mediators effectively can prevent CVD and all features of MetS (Huang, Y & Liu 2014). For dietary approach usually the global
guidelines suggest the dietary patterns as recommended by ‘Dietary Approach to Stop Hypertension’ (DASH), or so called Mediterranean, diet (Eckel et al. 2013).

Lifestyle approaches are multifaceted and cost effective and hence are strongly recommended to be introduced early, aggressively and maintained throughout every stage of disease. For example, progression of MetS or pre-diabetes to categorical diabetes can be markedly delayed by lifestyle therapies (Grundy 2006). Further lifestyle interventions minimise the need for multiple drugs and also delay the need for initiating drug therapy for many years without impairing long-term clinical outcomes (Eckel et al. 2013; Grundy 2006).

The evidence suggests that the therapeutic lifestyle that includes the combination of dietary patterns with physical exercise exert favourable effect on all individual features of MetS (Huang, Y & Liu 2014). These evidences are compelling because of non-toxicity and superb efficacies compared with medication and hence are imperative to be introduced at every stage of the diseases, nonetheless adherence is questioned (Grundy 2009).

3.5 Therapeutic Approach of Mind-Body Medicine and Metabolic Syndrome

The central pillar of the therapeutic approach of mind body medicine is behavioural modification employ structural mental activities that contribute to cognitive restructuring, positive appraisal and self-awareness that facilitate adaptation and result in stress reduction (Linden & Moseley 2006). The meaningful potential of mind body medicine therapies with exacerbated stress and BP reduction have been well documented in meta-analysis and review studies that suggest autonomic restoration, enhance relaxation and improved quality of life as an additive benefits (Dickinson Heather et al. 2008; Dickinson et al. 2006; Ospina 2007; Rainforth et al. 2007).

On the other hand, there is great paucity of evidence suggesting the potentials of these therapies in MetS. Currently there is only one published review with 3 clinical trials and has documented positive effects of mind-body medicine in MetS. The review suggested the feasibility and acceptability of these therapies for
managing symptom cluster of MetS. The review further suggested that the interventions rapidly reduce the devastating symptoms of these chronic conditions through facilitating regulatory activities (Joel 2011). Interestingly, of the three studies that were included in the review, two studies have investigated yoga practices while one investigated yoga type meditative technique (Transcendental meditation). The promising lead role of yoga practices in reducing all clustering features of MetS simultaneously have further been investigated in a substantial number of studies with positive outcomes (Cohen, BE et al. 2008; Kanaya et al. 2014; Khatri et al. 2007; Manchanda et al. 2013) and these changes were more profound with change in dietary patterns (Harbans, Anjali & Smita 2011).

This chapter so far has discussed the consequences of stress in the development of MetS and its management strategies. The efficacious role of mind-body therapies exemplifies the potential of yoga practices to influence all clustering features of MetS. In order to establish the clinical relevance of yoga in mitigating the features of the syndrome more rigorous studies are needed. These studies have to indicate that the specific functional mechanism through which these practices work, directly influences stress regulatory system and have symptom specific effects.
Yoga refers to that enormous body of spiritual values, attitudes, precepts, and techniques that have been developed in India over at least five millennia and may be regarded as the very foundation of the ancient Indian civilization. Yoga is thus a generic name for the various Indian paths of ecstatic self-transcendence – the methodical transmutation of consciousness to the point of liberation from the spell of the ego personality. Yoga, the unified condition of ecstatic state (samadhi) is the hallmark of yogic path that unanimously confirms mental lucidity (Feuerstein 2002, Pg 7).

This chapter exploring the historical and modern background of yoga will provide an overview of yoga from a modern perspective. Further the chapter will explore the current literature on the psychophysiological effects of yoga. The section will further develops an understanding of how yoga techniques result in rich foundation of mind-body integration and may protect health, serve to prevent disease and even reverse the remodelling of many physiological pathways which are known aberration of psychophysiological flexibility. The chapter will identify the gaps within the framework of the objective of this thesis and provide the justifications for the research undertaken in this thesis.

4.2 Definition of Yoga

Yoga is a generic term and is used for all Indian spiritual endeavours and its essence is enlightenment. The concept of yoga is so broad and malleable that it can be used to describe nearly any practice or process one chooses. This is partially because every group and every age has created its own version of yoga (White 2012). Yoga has an exhaustive list of meanings, and in derived from Sanskrit etymology ‘yuj’ that has various connotations including binding, joining, attaching, yoking, harnessing, focusing and perfection. For instance, the Bahrgava’s Standard Illustrated Dictionary: Hindi-English, has defined yoga using numerous words such as:
Yoga: n. mas. One of the six schools of Hindu philosophy, a union with the Universal Soul by means of contemplation, means of salvation, the 27th part of a circle, a sum (arith), total, profound meditation to earn and enhance wealth, unity, conjunction, union, combination, mixture, contact, fitness, property, an auspicious moment, plan, device, opportunity, recipe, connection, love, trick, deception, as a suffix used in the sense of ‘capable, fit for’ (Roy 2012, Pg 633-634).

Yoga is frequently interpreted as the ‘union’ of individual self-consciousness or relative reality (jīva-atama) with Supreme Self-consciousness or Ultimate Reality (parma-atma) which comes from Vedanta, another prominent branch of Indian philosophy. Indian sages and scholars have provided a variety of intricate definitions: restraining the mental modification (Patanjali in Yoga Sutra); yoga as separation or discernment (Bhojvritti); union or equanimity (Vedanta); evolution (Sri Aurobindo in Synthesis of Yoga) and ecstasy (Sage Vyasa in Yoga Bhasya). Similar variability in the definition of Yoga is reflected in the Bhagavad Gita in Hinduism’s equivalent to the New Testament, according to which ‘yoga is perfection of skill’ or action, Yogah karmeshu kaushalam (Sivananda 1962, Pg 10), while in the same book another verse (chapter 2 verse 28) describes yoga as Samatvam yoga uchyate explaining that yoga is synonymous with ‘yoga is equanimity’ or balance (Sivananda 1962, Pg 8).

4.3 Background of Yoga

Yoga is a complex philosophy of transcendental consciousness with comprehensive historical and philosophical background. Yoga as a self-regulatory application and in its oldest form appears to have been the practice of discipline, introspection, or meditative focusing in conjunction with rituals. There is an ongoing debate for the origin, history and practices of yoga that flourished sometime between 150 and 500 CE, that it is influenced more by the Indian Vedic tradition which is patriarchal or the Tantric tradition, another indigenous prominent culture of India which is matriarchal (Frawley 2009, Pg 236). However, both are one, though with different orientation.

The tradition of yoga is greatly attributed to the sage Patanjali who, in around 500 BCE, compiled and systematised the prevailing yoga practices by encapsulating them into 196 aphorisms in his classic work the Yoga Sutra. This
classical tradition is largely known as path of *Raja* yoga or *Astanga* yoga (eight limbs), and is important because it was the first systematic and comprehensive treatment on the subject of meditation (Adiswarananda 2008). Virtually ignoring physical aspect of yoga this tradition do not speak of postures and breath control and is far more concerned with the control of the mind and salvation through meditation (White 2012).

The path of *Raja yoga* mainly elaborates the eight limbs which are: moral observance (*Yama*), self-discipline (*Niyama*), Posture (*Asana*), Breath regulation (*Pranayama*), sensory withdrawal (*Pyatayahara*), concentration (*Dharana*), meditation (*Dhayana*), Mergence (*Samadhi*) (Vivekananda 2007). These limbs are further briefly described within the framework of modern perspective (See section 4.4.3).

Historically, yoga was much broader and comprehensive and the practice of yoga was understood to be contemplative practices that aimed at one thing – to alleviate suffering and promote optimal physical and mental thriving. Thus to achieve the goal, the practice of yoga included a wide range of paths oriented to, self-less devotion (*Bhakti yoga*), self-less knowledge (*Janana yoga*), selfless service (*Karma yoga*) and selfless discernment and meditation (*Raja yoga*). Each path offered practices to mitigate suffering distress and produce higher level of consciousness (Feuerstein 2002). These four paths could be considered as the aspect of a ‘whole’ that is called ‘yoga’ (Saraswati, N 2002) as the line separating them has never been always clear. The major commonality among these various paths is training and discipline of mind and mental though process that appear to be the fundamental aspect to promote wellbeing and balance amongst mind-brain-body functions. Swami Rama said:

> The secret of health for both mind and body is not to mourn for the past, worry about future, or anticipate troubles but to live in the present moment wisely and earnestly (Rama 1999, Pg 32).

The diversity sprang from the period between 6th and 16th century CE and the period belonging to the development of the post classical tradition of physical/body culture and includes the orientation of *Hatha yoga* (yoga of force)
(Feuerstein 2002). This interesting turn occurred when some adepts began to probe the hidden potentials of the body in order to withstand the onslaught of distress and continue experiencing transcendental realisation. Hence under the influence of alchemy the new breed of yoga masters created a system of practices designed to rejuvenate the body and prolong life.

Whereas, the ideal path of Raja yoga is to develop the dormant potentials within human personality, the ideal path of Hatha yoga elaborated upon postures (asanas), breathing (pranayama), cleansing techniques (shatkriya), energy point (chakras), serpent power (kundalini), internal locks (bandha), sheath (kosha) and nerves (nadi). Despite the diversity within yoga tradition, these approaches agree on the need for self-transcendence.

4.4 Overview: Conceptualisation of Modern Yoga

Although Yoga is regarded by many as a transcendental science, it has become the subject of philosophical speculation and more general academic study. More recently it has become the object of mundane scientific research and investigation (Alter 2009, Pg 35)

Today yoga is a global phenomenon and the yoga that is taught and practiced in typical modern classes has very little in common with ancient yogic scriptures and treaties. After several metamorphoses, yoga from spiritual endeavour (sadhana) turned into physical endeavour (kaya sthiryam or kaya sadhna) and now largely recognised as Hatha yoga, an amateur version of which is widely practices throughout the world (Feuerstein 2002).

Since its introduction to the Western world, yoga has gradually progressed to become diffused throughout society and from 21st century onwards, it has been modernised, commodified, medicalised and transformed into the system of yoga and physical culture seen today. Today, nearly all the assumptions about yoga date from the past 150 years and very few modern-day practices date from before the 15th century.

The practice and understanding of yoga has changed and grown, adapting to new socio-cultural conditions. Modern yoga is a complex discipline that can
involve corporeal concern as well as philosophical concern – *modern postural yoga* mainly attributed to *Sri T. Krishamacharya* and *modern meditational yoga* mainly attributed to *Swami Vivekananda*. However, both of which flourished from 1920 onwards (White 2012).

The modern postural style, which has strong emphasis on postural practices, has contributed the most to developing and codifying relatively advanced cannons of postural theory and practice (Singleton 2010). In this sequence the legacy of Sri T Krisnamacharya is reflected in the dynamic series of *Ashtanga yoga* of Pattabhi Jois, alignment of BKS Iyenger, classical poses of Indra Devi or the customised *Viniyasa* of TKS Desikachar (Ramaswami 2005) to name a few.

The situation is complex with regard to meditational yoga that has styles and focuses primarily on their own specific set of meditational practices. These said styles are often headed by charismatic founders or leaders whose authority pervades the institution. The teaching stimulates the creation of specific practices or specific interpretations of practices. This then brings the practices progressively closer to the denominational forms of yoga where groups promote their own forms, such as Transcendental meditation (TM), Sivananada Yoga, Art Of Living (AOL), Sri Chimmoy Mission and International Society of Krishna Consciousness (ISKCON) (Singleton 2010; White 2012).

Of the many branches that developed concurrently within the realm of yoga, this section emphasising the pragmatic approach will focus on Raja yoga and Hatha yoga. First, these approaches substantially contributed to the yogic dimensions with their systematic structural techniques. These techniques in turn contribute to affect emotional, behavioural and self-regulation. Second, these approaches have a wide prevalence in modern day practice as most of the current styles are a blend of these two hallmark approaches of yoga. Finally and importantly most of the scientific investigations have focused on yoga posture, yoga breathing or yoga meditation or a combination of these.
4.4.1 Raja Yoga

Raja yoga means royal yoga and the name is comparatively late nomenclature in order to distinguish it from Hatha yoga. Raja yoga is primarily cognitive and described as the stilling of distorted fluctuations or ruminations in the mind which are the source of suffering. The multicomponent, the eight step process of Raja yoga, is aimed to turn the mind to be effortlessly quite, focused and self-aware. These cognitive goals overlap other mediative traditions that developed in India such as Buddhism and Jainism and from this the modern concept of mindfulness has sprung (Feuerstein 2002).

The eight limbs of Raja yoga offer eight different practices that are aimed towards self-control and self-regulation. Collectively, these eight limbs may be conceptualised as methods to regulate emotions, thoughts or behaviour, cognition and to increase well-being (Gard et al. 2014).

4.4.2 Hatha Yoga

The principal objective of Hatha yoga is to engender the retention and union or balance of the two modes of prana (energy): ha (sun in Sanskrit) corresponding to pingla nadi or prana shakti, the dynamic force; and tha (moon in Sanskrit) corresponding to ida nadi or citta shakti, the passive aspect. These two energies are sometimes interpreted as solar and lunar energy, which are believed to flow in the human mind–body and to govern life (Saraswati, N 2005). Hatha yoga scriptures compare the body to an unbaked earthenware pot which must be baked in fire of yoga to purify it (Singleton 2010). Hatha yoga suggests that elimination of impurities from physical and mental bodies is conducive for the higher practices of Raja yoga. The opening verse of the hallmark book Hatha Yoga Pradipika explains that Hatha yoga is the first step leading to the heights of the Raja yoga. The verse translates as:

Salutation to the glorious primal guru, who instructed the knowledge of Hatha-Yoga which shines forth as a stairway for those who wish to ascend to the highest stage of Raja-Yoga (Muktibodhananda & Saraswati 2005 pg. 23).
The traditional *Hatha yoga* texts are sometimes divided into six, seven or eight limbs but these are not identical to Patanjali’s eight limbs. However, in modern day practices *Raja yoga* techniques have been amalgamated with *Hatha yoga* techniques. A striking feature of the yoga commonly taught today is the degree to which it departs from the model as outlined in traditional texts. *Asana, Pranayama, Pratyahara* and *Dhyana* are usually considered the four essential components of contemporary yoga practice.

The following section provides a concise overview of the eight essential limbs of yoga from the modern day and the research perspective with physiological relevance.

4.4.3 Philosophical and Physiological Relevance of the Limbs of Yoga

**Ethics (Yama and Niyams):** On the foundation of the yogic path of self-regulation lie ethical and moral precepts which are examples of the standards or guidelines that contribute to emotion and self-control. These ethical precepts are the first and second limb respectively of *Raja yoga*. Such ethics suggest that yoga is devoid of religious connection. They are not based on moral values, judgement of right and wrong but are rather seen as action that helps to quite an overactive mind, regulate emotions and enhance skill-full behaviour (Cope 2006). *Yama* refers to ethics regarding the outside world and therefore are of particular importance in social context. This comprises of non-violence, truthfulness, non-stealing, moderation of senses and greedlessness. Whereas, *niyam* refers to ethics regarding the inner world. *Niyama* comprises purification or cleanliness and contentment, austerity, self-reflection and surrender or devotion (Saraswati, N 2002).

**Postures (Asana):** In Patnajal *Yoga Sutra* the *asana* is the third limb and is defined as “sthiryam sukham aasanam” (Chapter 2 verse 46) that explains steady and comfortable posture (Vivekananda 2007, Pg 213). Postures are one of the most commonly utilized yoga practices in modern interpretations that have been acquired from *Hatha yoga*. Physically challenging postures are further described as being sustained through the fluctuations of the mind. Historically postures were used to control the body in preparation for controlling the mind in meditation for
extended periods of time (White 2012). A typical modern yoga practice includes a series of postures targeting different parts of body. Common premises behind practising various postures is that it may help to improve physical flexibility, muscle toning as well as reduce physical and emotional stress (Büssing et al. 2012). Yoga manuals such *Light on yoga* (Iyengar 2012) often suggest a connection between emotional states, physical health and postures, although, this link has not scientifically been established for any particular posture (or set of postures). However, there is emerging evidence from brain imaging studies that a single session of yoga postural practice leads to changes in brain areas which regulate emotions, cognition and behaviour with regular yoga practitioners which did not occur during the control session of reading (Streeter et al. 2007). This thesis aimed to investigate the effects of physical postures on modulating cardiovascular, metabolic and autonomic regulatory activities.

**Breath Regulation** (Pranayama): In Patanjali’s *Yoga Sutra*, the *pranayama* is the fourth limb. *Pranayama* is a Sanskrit word constructed of two separate words, *prana* meaning breath, respiration, life, vitality and energy, while *ayama* can be translated as restraint, control manifestation and regulation (Saraswati, N 2005). Hence *Pranayama* is a series of specific techniques to control the breath in order to allow the breath and life force to flow freely (Sovik, Mayer & Saper 1999). *Yoga Sutra* defines *pranayama* as: ‘*Tasmin sati svasa parasvasayoh gativicchedah pranayamah*’, (Chapter 2, Verse 49) that explains the incoming and outgoing flow of breath with retention (Vivekananda 2007). The practise of *pranayama* has been acquired from *Hatha yoga*. Two benefits of the pranayama are described to help practitioner in decreasing arousal and increasing awareness of the interaction between body and mind (Sovik, Mayer & Saper 1999). Similar to *asana* as preparation of the body for meditation, *pranayama* is meant to prepare the mind for meditation. *Pranayama* differs from normal breathing on a number of dimensions, such as duration of the inhalation and exhalation, the holding of the breath and the ratio of these. All *pranayama* involve diaphragmatic breathing, mostly deep and slow in quality through nose (Jerath et al. 2006; Telles & Naveen 2008). The practice of pranayama is well known, and the scientific evidence collaborating these ancient breathing techniques have reported improved in pulmonary functions and cardiovascular profiles (Jerath et al. 2006). This thesis
aimed to investigate the effects of yogic breathing on cardiovascular, metabolic and autonomic activities. In a review report, Tyagi and colleagues have suggested that periods of breath retention in yogic breathing and frequency of yogic breathing have profound effects on metabolism and HR (Tyagi & Cohen 2013).

**Meditation (Pratyahara, Dharana, Dhayana, Samadhi):** Postures and breathing practices are traditionally described to support and foster meditation practices. These are consecutively the fifth, sixth, seventh and eighth limb of Patnajlai’s *Yoga Sutra*. However traditional yoga texts describe the triad ‘Dharana, Dhayana, Samadhi’ to attain total absorption called Samyam, or a state of culmination of yoga (unification or oneness/ stillness) (Vivekanananda 2007). Whereas Pratyahara, Dharana, Dhayana are the key stages of meditation. Yoga texts suggest that Dhayana cannot be experienced by a restless mind or a fragmented mind. Therefore dharana must be undertaken after mastering pratyahara. With perfection of dharana, dhayana becomes a spontaneous, ongoing process that ultimately leads to Samadhi. This is where a wonderful and luminous state of consciousness unfolds, called Samyam (Saraswati, S & Saraswati 2005, Pg 260-261).

Within the yoga tradition, the meditative techniques as described in the *Raja yoga* help the practitioner begin to see the conditions that lead to distress, such as mental and emotional sufferings (fluctuations) and the conditions that remedy suffering (i.e mental stillness). Suffering/pains/distress is further described in *Yoga Sutra*, as a time when the mind is in an afflicted state (*Klesha*). That is, either avoidance in grasping the knowledge of ones’ true-self (Avidya), grasping onto an experience or being judgemental (Asmita), not wanting to let it go (*Raga*), experiencing aversion (*Dvesha*) and trying to push some experiences or objects away with force (*Abhinivesha*) (Gard et al. 2014). In both cases how one relates to one’s inner experience will create either more or less suffering. Suffering is also described as a mental state that prevents the mind from seeing reality without emotional bias (Rama 1996). The ability to see reality clearly without bias through meditation practice is a revered tool of self-control and self-regulation within the realm of yoga that leads to unification or oneness (Rama 1996).
Of the various forms or stages of meditation, *Pratyahara* refers to withdrawal of senses or directing the senses inwardly. *Yoga Sutra* defines *paratyahara* as: *Svavishyaasamprayoga chittasyasvaroopaanukaara, ivendriyaanaam pratyahaaraha*, (chapter 2, verse 54), that explains a way to minimise external distraction from sensory information, facilitate a calm mind and allowing attention to turn inwardly (Vivekananda 2007). A typical modern day yoga practice that includes the supine rest pose (*Shavasana*), an emphasis on the body to be relaxed and eyes closed, is a form of *pyatahaara*. This technique also includes guided relaxation (*Yoga Nidra*), which serves as an invitation for the practitioner to draw their attention to their inner being (Gard et al. 2014).

The next step in meditation is called *dharana*, which means to hold. *Yoga Sutra* defines *dharana* as ‘*deshbandhshchittasya dharana*’ (chapter 3, verse 1), that explains focusing the mind to one place, thing or experience (Vivekananda 2007). The practitioner during this stage of meditation aims to focus the mind on a single object of meditation such as breath, a point of the body, or external object and attempt to maintain focus on that object. At this stage, focused attention requires effort as the mind repeatedly wanders. The important goal of *dharana* is to minimize mind wandering. Such focused attention is the centre of relaxation responses (Benson 1975) and mindfulness meditation (Salmon et al. 2009). Similar to yoga, these techniques also emphasise that when a practitioner realizes the mind has turned away from the object of focus of meditation, the mind is deliberately and continually bought back to the object of focus (Gard et al. 2014).

*Dhayana* occurs when the mind ceases to wander. *Yoga Sutra* defines *dhyana* as *Tatra pratyayaikatanata dhyanam*’ (Chapter 3, verse 2), that explains a steady effortless attention or unbroken flow of attention (Vivekananda 2007). This advanced stage of meditation occurs with time, practice, and wandering decreases, as does effort to maintain focus, and an unbroken chain of awareness rests on the object of meditation (Feuerstein 2002; Telles & Singh 2013). The mind begins to become completely absorbed in the object of attention and a sense of union with the object of attention begins to occur (Cope 2006). An analogous process corresponds to the *Flow state*, as described by
Csikszentmihalyi (2008), and is often observed in advanced athletes (Csikszentmihalyi 2008) and musicians (Khalsa et al. 2009).

This further leads to the final meditative limb, *Samadhi*. The *Yoga Sutra* defines *Samadhi* as ‘Tadevathamatranibhasam svarupashunyamiva samadhi’ (Chapter 2, verse 3), that explains transcendent state of self-conscious awareness or absorption (Vivekananda 2007). The literal meaning of the term *Samadhi* is placing or putting together. *Samadhi* is both the technique of unifying consciousness and the resulting state of ecstatic union with the object of *dhyana* (Feuerstein 2002, Pg 4). *Samadhi*, has been described as an experience of no conceptualization. This state of meditation offers a deep sense of interconnection and ‘sameness’ with all phenomenon (Cope 2006). Swami Satyananda describes the state of *samadhi* as sublime equanimity (Saraswati, S 2005).

The experiences of *Dhayana* and *Samadhi* are said to have profound effects on mind and physiology and that may even defy beliefs and capabilities by extending the potentials of the human body. The exceptional amazing control has been demonstrated by several advanced yogis who pushed the limits beyond, revealing extraordinary control on cardiovascular, metabolic and autonomic system (See section 4.5). However explicitly these practices specifically are not taught in typical yoga classes. Rather these meditative limbs are offered as a process of meditation. With consistent and continued efforts the practitioners may escalate from the stage of *Dharana* to *Samadhi*. This thesis aimed to investigate the effects of these meditative aspects on cardiovascular, metabolic and autonomic regulatory system.

### 4.5 Feats of Yoga

The advancement of scientific technology, bio-signalling and imaging techniques have allowed unravelling of the mysteries of the mind’s ability to exert extraordinary control on bodily processes. These processes have been exhibited by several yoga experts from time to time. The physiological control demonstrated by these adept yogis/meditators have only been highlighted in case studies or by social media, which are briefly outlined below.
For instance, advanced meditators in meditative conditions generating body heat dried the wet sheets wrapped on their back in near freezing (<3°C Celsius) weather (Cromie 2002). While another group with similar meditative techniques demonstrated both increases and decreases in metabolism by over 60% (Benson, Malhotra & Goldman 1990). Similarly in two separate studies the advanced yogis demonstrated remarkable reduction in metabolism during the prolonged stay in air tight pit. Of this one report documented the remarkable similar reduction on two consecutive sessions during the stay of 10 hours each (Anand, Chhina & Singh 1961) while the other report documented reduction by 40% in oxygen consumption without any symptom of tachycardia or hyperpnoea (Craig 2002). Further, another report documented advanced yogis revealing the ability to tolerate the ambient carbon dioxide level of more than 7% and oxygen level less than 12% (Karambelkar, Vinekar & Bhole 1968). Furthermore, a different study documented a 70-year old adept yogi who remained confined to a small pit for eight days. Recoding wires showed that his heart rate remained below measurable sensitivity of the recording (Kothari, Bordia & Gupta 1973). Additionally there are reports of a yogi demonstrating a simultaneous increase and decrease in the temperature of the right palm, with the difference in temperature reaching up to 6% Celsius (Green 1977, pg 197-218).

More recently, the media reports of a young ‘Buddha boy’ baffled scientific community by spending extended periods of months meditating beneath a tree allegedly without food and water. Another report of an 82-year Indian yogi claims to have lived without food and water since 1940, which was confirmed by hospitals (Discovery 2008).

These challenges of extending limits of human endurance and physiological control are puzzling. World class athletes are also constantly surpassing the perceived limitations of the human body and breaking the records achieving impossible, such as Stig Severinsen holding his breath underwater for 22 minutes (Wikipedia 2014). Moreover, the concept of breathareians people who claim to sustain themselves solely by prana or by the energy of sunlight is incomprehensible. Each of these accomplishments of human ability show that the
body’s capacity may be greater than the physiologist, scientists and researchers believe.

However, the evidence of yoga adepts undertaken in laboratory condition are poorly documented, most of the studies are either single case studies or have involved a small cohort and are also not peer reviewed studies. Some of the documents are even the media reports which have not been subjected to measure and validated under extreme condition. These investigations however do require further investigations and documentation with advanced measuring scientific equipment in order to provide clues about extending the limits of human endurance and potentials of cardiac, and metabolic and autonomic control. These investigations may provide direction to mind-body integration in managing stress-related disorders.

4.6 Yoga and Balance

‘The belief that we cannot, and we do not, control certain parts of our body is false. The truth is that we have absolute control over our body. The problem lies in whether or not it is conscious or unconscious. Unconscious control means habit-conscious control means choice! (Nuernberger, Science & Philosophy 1981, Pg 121)

In the doctrine of unity, yogic state may be characterised as harmonious state of experience when mind, body and breath are united in a feeling of wholeness and action and awareness effortlessly merge (sameness). This state in yogic text is often described as ‘luminous state of consciousness’ (Saraswati, S & Saraswati 2005) that unfolds human potential through natural means (Vivekananda 2007). Physiologically this state in dynamic balance is defined as least excited state (Wallace, Benson & Wilson 1971) or alterful rest (TellesYadav, et al. 2013).

The multiple yogic tools (physical and mental) are of great utile, as progressively these tools directing the attention inwardly, harness the thought process and that may result mind-body integration. First these tools facilitate clam behaviour, second allow minimal mind wandering, third lead to unbroken focus (effortless sustained attention/flow) and further turn into deep sense of interconnectedness or mergence with the activity (Gard et al. 2014). This optimal state is inexplicable and incomprehensible and is acknowledged as a state of
perfection (Rama 1999). Thus yoga practitioners performing the task with optimal performance are adapted to remain calm, in a state of balance and maintain homeostatic regulatory activities efficiently (Telles & Singh 2013). Recent evidence suggests that focused attention has salutary implications in reducing distress, aging and promoting longevity (Epel, E et al. 2009; Epel, ES et al. 2012).

In early scientific research in India with advanced yoga practitioners, Bagchi and Wenger (1957) wrote:

physiologically Yogic mediative practices represents deep relaxation of the autonomic nervous system without drowsiness or sleep and a type of cerebral activity without highly accelerated electrophysiological manifestation, but probably with more or less insensibility to some outside stimuli for a short or long time (Bagchi & Wenger 1957 pg 146).

Subsequently, in series of neurophysiological studies Telles and colleagues investigated various yoga techniques demonstrating that yoga practices facilitate discrete ‘forms’ of thoughts, that usually occur with relatively uniform state of mind resulting to dynamic neural changes. The authors anticipated that these changes may alter autonomic regulatory activities and enhance performance in a variety of cognitive tasks (Telles et al. 1993). Further in sequence, Telles and colleagues documented these dynamic alterations in neural activities may occur from ‘stimulus based stimuli’ such as meditation, breathing, focused concentration or meaningful repetition of a word ‘mantra’ (Telles et al. 1994). In this series authors further suggested that these modulations enhanced the ability to be cognitively attentive on a certain task and sustained attention for prolonged period with least minimal effort and improved performance of that activity (Joshi & Telles 2009). Further in a recent study, Telles and colleagues (2013) found that yoga practices led to minimize the errors in the task or activity, thus the authors speculated that ‘yoga trains practitioners with awareness and relaxation, and this helps practitioners to perform attentional task with fewer attentional resources’ (TellesYadav, et al. 2013, Pg 90).

These results implicate yoga practices in allowing practitioners to have ability to shut down mental activities in all information channels that are irrelevant for task fulfilment. Thus the ‘yogic state’ which corresponds to mind-body coherence,
is the state of optimal internal balance that reflect peace, balance, attention and resilience, which is a unique functional hypometabolic condition. This state could be likened to the psychological states of Flow which fosters the concept of dynamic balance when challenges and capacity are equally matched (Csikszentmihalyi 2008). One can call this state of internal and external connectedness or coherence.

4.6.1 Implications of Yoga and Flow Experience

The harmonious state of flow having strong similarities with eustress (Selye 1983) has an active and protective role in stress coping process (Peifer 2012). Flow state described as a functional state of optimal experience is a unique affective, attentional condition that includes feeling of motivation, high energy and immersion in the task during activity and may be vital from psychophysiological perspective as it enhances health wellbeing (Peifer 2012). Often this state correlated and occur during sports performance (Csikszentmihalyi 2008) and musical performance (Khalsa et al. 2009). The common attributes of flow experience and yoga experience appear to be the emphases on cognitive strategy, attentional control and absence of self-referential thought which in turn is speculated to enhance optimal performance and enhance human potentials (Peifer 2012). However despite strong similarities between flow and yoga the flow experience has never been examined in yoga practitioners. This thesis aimed to investigate the experience of flow in regular yoga practitioners.

4.7 Use of Yoga

In 2007, the National Centre for Complementary and Alternative Medicine (NCCAM) conducted the National Health Interview Survey (NHIS). The survey reported that yoga was among the top 10 commonly used complementary and alternative medicine (CAM) therapies tried by more than 13 million US adults and overall 16.6% of United States adults (34.1 million people) used at least one mind-body complementary and alternative medicine. Furthermore the survey reported that, compared to previous surveys, the largest increase among CAM therapies was reported in the use of yoga with an increase of more than 3 million
people (Barnes, Bloom & Nahin 2008). This survey was followed by the 2008 *Yoga Journal* Survey, which found that 15.8 million (6.9%) US adults had tried yoga (Yoga Journal 2008) and Furthermore the survey of 2012 reported an increase of 29% in the use of yoga with 20.4 million people practising yoga (Yoga Journal 2012).

Stress management and physical flexibility/muscle tone are among the top reasons for practising yoga. The results of national survey ‘Yoga in Australia’ (2006) reported that physical flexibility and muscle tone was the most prominent reason for people to practice yoga (86.5%) and that was followed by stress reduction and anxiety (79.4%) (Penman et al. 2012). Similar results for the reason of practising yoga are reported in another survey ‘Yoga in America’ 2012. The results reported, the most prominent reason for yoga practice was physical condition and flexibility with 78.3% while 59.6% people practiced yoga for stress relief (Yoga Journal 2012). Furthermore, a survey in Germany involving internal medicine patients reported 12.2% patients used yoga for their primary medical complaint with the majority finding yoga to be helpful in dealing with their complaints (Cramer, Holger et al. 2013) Interestingly these surveys altogether reported that yoga users are mainly females and well educated, coming mostly from urban areas and possessing the primary intent through practice to enhance physical flexibility.

### 4.8 Psychophysiological Benefits of Yoga Practices in Stress and Cardiovascular Diseases

This section will investigate the current available yoga literature that includes published reviews and empirical studies that have reported on stress, and cardiovascular risk factors and/or features of MetS. Further the section exploring the gaps in the literature will raise the question that will set the ground for further chapters of this thesis.

Yoga is a relatively safe and gentle physical activity for promoting general health and a state of behavioural well-being for sedentary individuals who have special health concern such as established CVD, obesity and musculoskeletal problems that can limit their mobility and tolerance to highly demanding physical exercises. An
individual may experience different kinds and degree of physical health benefits and improvement in functional capacity depending on how they practice yoga (Lau et al. 2012, Pg 3)

The growing popularity, apparent potentials and synergistic effects of yoga practices alone or in combination hold promise as therapeutic intervention in health promotion (Woodyard 2011). In recent years efforts are being made in order to incorporate yoga in the health care system as treatment option to alleviate both mental and physical problems (Büssing et al. 2012). It is conceived that yoga alters the degree to which events are experienced stressful or may even influence the reaction to perceived stress. The substantial body of reviews and empirical studies acknowledge the benefits of yoga, however there still appears lack of strong evidence to determine clinical relevance of yoga in stress and stress related medical conditions such as cardiovascular diseases.

Further relatively recent standardised yoga interventions such Silver yoga and Medical yoga have been developed for clinical settings to facilitate adaptation in the people with medical conditions and/or restricted physical movements. It is likely that these interventions may produce consistent results hence facilitating the greater understanding of yoga mechanism in mitigating stress. However these interventions, yet have been studied on a very small scale (n=6) with limited number of population and relatively are of small duration. In addition these studies mostly relied on self-reported psychometric measures identical to all the published review studies reporting on stress (n=3).

Although the psychometric (subjective) measures are relevant to health outcomes but the use of these measures for empirical analysis however has been confronted with strong scepticism (Jahedi & Méndez 2014). Whereas physiological measures recorded with near - perfect fidelity over time contribute to index both, psychological states as well as physiological states (Blascovich 2004). Hence in order to determine the validatory effects of yoga as regard to perception of stress and that therefore may accurately reflect the psychophysiological status, it is prudent to measure the stress responses in terms of physiological measures. Some of the physiological measures such as OC and
HRV are considered the window to autonomic, metabolic and cardiovascular regulatory activities thus indicating the accurate status of health and wellbeing.

### 4.8.1 Effect of Standardized Yoga Protocol and Stress Symptoms

With overlapping key components - ‘postures, breathing, meditation and /or relaxation’, the standardised clinical yoga practices that involve gentle movements are specifically tailored to adapt to clinical conditions and older adults. These interventions have been subjected to investigate in a very limited number of studies (n=6) with studies indicating moderate effect on physiological measures hence the efficacy of these practices appears vague in stress related symptoms.

In a 12 week- controlled trial, involving patients with stress related symptoms either randomized to the Medical yoga for 60-minutes/week maintaining usual standard heath care (n=18) or control with usual standard care (n=19), Kohen and colleagues found significant improvements in stress related psychological measurements in yoga group compared to control. However the study did not report any significant difference between the groups in physiological measures such as BP, HR and peripheral oxygen saturation (Kohn et al. 2013). Further in a series of small studies involving elderly population (>60 years) with stress related symptoms, Chen and colleagues suggested that Silver yoga program produced significant improvements in psychological measures such as stress symptoms, functional capacity and cognitive improvement as well as improvement in physical flexibility and balance (Chen, K-M et al. 2008; Chen, K & Tseng 2008; Chen, KM et al. 2009; Chen, KM et al. 2010; Chen, KM et al. 2007). Conversely, not all studies employed physiological measures and in parallel the improvements in these measures such as BP, cardiovascular functions and body composition were reported from moderate to non-significant (Chen, K-M et al. 2008; Chen, K & Tseng 2008; Chen, KM et al. 2009; Chen, KM et al. 2010)

With these less conclusive findings it is difficult to explicate the clinical utile of yoga practices in stress and pathological conditions. The following section explores the review studies on yoga and stress.
4.8.2 Review Studies on Effects of Yoga on Stress

Since it is the self by which we suffer, so it is the self by which we find relief (Nuernberger, Science & Philosophy 1981, Pg 20).

There is paucity of reviews (n=3) that have investigated the effects of yoga practices on stress. These reviews report yoga as cost effective and possible option in conjunction or supplement to pharmacological therapy. Reports stipulating yoga supplementing pharmacological treatment are less conclusive suggesting the clinical relevance of yoga in stress and stress related symptoms.

In a systematic review of involving 17 studies that ranged from single session to 6 months, Sharma and colleagues (2012) suggested positive significant changes in stress symptoms. The review found that psychological measures were incorporated in 16 studies while the physiological measures were employed in 9 studies with readily measured variable being HR (n=6) followed by BP (n=5), BP (n=4) and HRV (n=2) (Sharma, M, Haider & Bose 2012). Further, in a review that included 8 randomized controlled trial (RCT) ranging from 3 days to 10 months, Chong and colleagues (2011) suggested yoga as an effective intervention for managing stress in health and found yoga to be as effective as African dance, cognitive behavioral therapy, and muscle relaxation in reducing stress. The review found all included studies reported on psychological variables, while the physiological and /or biochemical variable were employed in 3-RCT’s and most readily physiological variables included HR, OC, body flexibility, muscular strength and endurance (Chong et al. 2011).

In contrast, in a review report including 35 studies that ranged from single session to 5 months Li and colleagues (2012) reported improvements in psychological symptoms of stress and anxiety. However the authors suggested that of the total studies 14 studies investigating physiological and biochemical markers of stress reported no significant effects in HR and BP as well as cortisol levels with yoga interventions. The author concluded yoga being a safe intervention with good compliance, improving quality of life and complementing pharmacological treatment (Li & Goldsmith 2012).
There has been limited inclusion of physiological measures compared to psychological measures in stress related symptoms. Some studies have developed their own invalidated questionnaires (Li & Goldsmith 2012). This together with an array of subjective assessment being used as investigation tools, such as perceived stress score, general health questionnaire, quality of life, profile of mood states, makes comparison more challenging and less reliable for generalized effects across populations. Further, the individual differences in the experience or perception to stress and/or differences in the stress appraisal, the subjective measures are likely to have bias effects specifically while comparing different population group (Blascovich 2004). Hence these conflicting results restrict the understanding the draw any firm conclusion for the efficacious benefit of yoga.

The following section explores the reviews reporting on effects of yoga on cardiovascular diseases.

4.8.3 Review Studies on Effects of Yoga in Cardiovascular Diseases and Metabolic Risk Factors

.........however the yoga participants have tendency to use yoga as a CAM therapy to treat musculoskeletal problems rather than chronic diseases such as cholesterol problems. The low prevalence in the use of yoga might limit exploration of the therapeutic potentials of yoga” (Lau et al. 2012, Pg 7).

A substantial body of review articles (n=10) attest that yoga therapy may be of assistance in the prevention and management of cardiovascular disease. These reviews acknowledge yoga as an economical, non-invasive practice with negligible adverse effects and high compliance and report that yoga enhances adaptation and improves balance, flexibility and functional capacity.

In a review of 17 studies involving healthy and diabetic patients that ranged from 8 days to 24 weeks, Sharma and colleagues (2012) suggest that yoga holds a promise in the treatment of cardiovascular risk factors (Sharma, M & Knowlden 2012). Further, in a review that included 13 studies ranging from 2 weeks to 2 years Jaysinghe (2004) reported that integrated yoga practices have outstanding beneficial effects on all cardiac risk factors simultaneously (Jayasinghe 2004). In addition, Hutchiston and colleagues (2003) in the review with 6 RCT’s reported
that integrated yoga programs result in significant and clinically relevant improvements in cardiovascular risk factors and coronary heart disease (CHD) mortality and severity. The author suggested that these effects are more profound on lipid profile followed by body weight (Hutchinson & Ernst 2003). Similar supporting evidences are further found in another review, yielding 32 studies reported that integrated yoga program to be an effective intervention in improving all features of metabolic risk factors such as lipid profile, body weight, blood pressure and glycemic index (Yang, K 2007). Additionally, similar significant improvements in all cardiac risk factors as well as in oxidative stress, coagulation profile and pulmonary functions with yoga practices have been further reported in the review that included 25 studies employing adult clinical population with cardiovascular disorders (Innes & Vincent 2007). Furthermore, Innes and colleagues (2005) in another comprehensive review including 70 studies that involved both, clinical as well as healthy population strongly suggested yoga practices as an effective instrument with capacity to positively influence cardiovascular diseases. The authors suggested that yoga alleviate the effects of stress though reduction in the activation and reactivity of the SAM system and HPA axis (Innes, Bourguignon & Taylor 2005).

In contrast, considerable reviews with lack of strong evidence suggest uncertain applicability of yoga practices in multiple risk factors of metabolic syndrome and cardiovascular diseases. For instance, a recently published review and meta-analysis including 11 RCT’s concluded uncertain long term effects of yoga practices in prevention cardiac risk factors (Hartley et al. 2014). Similar inconsistent findings are reported in another review, concluding lack of insufficient evidences to evaluate the potentials of yoga for the prevention of CHD and cardiac risk factors (Lau et al. 2012). Further, unclear long term effects of yoga therapy are reported in diabetic populations despite profound positive short term improvements in multiple cardiovascular risk factors (Alexander 2010). In addition, Aljasir and colleagues (2008) in the review with 5 RCT’s reported modest change in glycemic index and lipid profile. However the authors suggested that definitive recommendation for inclusion of yoga practices in clinical setting cannot be encouraged as no study strongly confirm positive modification with yoga practices (Aljasir, Bryson & Al-Shehri 2010).
The reviews identified the efficacy of yoga treatment in complex cardiovascular diseases and risk factors with many studies analyzing the effects on healthy populations. However, several authors have suggested that there is insufficient evidence to include yoga into clinical settings as there is still some uncertainty around the ability of yoga practices to produce long term positive effects (Aljasir, Bryson & Al-Shehri 2010; Lau et al. 2012).

4.9 Limitations of Previous Literature

The disparities in the findings have been largely implicated to the variability in yoga styles, differences in individual components of yoga, short interventional duration that complicates the applicability of yoga uncertain in chronic clinical conditions. Li and colleagues (2012) in the review identifying design limitations in many of the included studies therefore recommended further studies with more appropriate design.

The previous section reports that the effects of yoga remain unclear in stress and stress related pathological conditions mainly due to disparities in the outcomes. Partially these inconclusive findings may be explicated due to the diversity in yoga styles, yoga techniques, short interventional duration and inclusion of healthy population as well as lack of comparison groups that make the applicability of yoga uncertain in chronic clinical conditions. Cramer and colleagues in a very recent bibliometric analysis of 312 studies found that yoga investigators in research have employed more than 40 different styles of yoga and that interventional duration varied from 1 day to 1 year (Cramer, Lauche & Dobos 2014). Further the author reported that of these studies 244 studies included yoga postures, 232 studies included yogic berating and 153 studies include meditation. This indicates that yoga practices may vary from pure meditative to pure physical. The yoga practice session may range from once in a week to two sessions per day (Elwy et al. 2014).

This heterogeneity not only makes the comparison of findings across studies difficult in determining the effects of yoga but also limits the researchers’ ability to understand the mechanistic pathways by which yoga reduces stress and affect
physical and mental well-being. Hence in order to determine the relevance of yoga practices it appears important to explore the separate effects of yoga postures, breath control, meditation and lifestyle advices. It is also yet uncertain to determine which aspect of yoga, if any, are effective in reducing the multiple features of metabolic syndrome.

4.10 Key Research Questions

The aim of this thesis is to explore the relationship between yoga, stress and psycho-physiology. Specifically this thesis aims to answer the following questions:

1) What is the effect of various yoga practices on blood pressure (BP) regulation, cardiovascular risk factors, oxygen consumption (OC) and heart rate variability (HRV)?

2) What are the metabolic and cardio-autonomic responses to stress in regular yoga practitioners, non-yoga practitioners and people with metabolic syndrome?

3) What are the effects of yoga practice on mood and flow states and how do they differ in yoga practitioners, non-yoga practitioners and people with metabolic syndrome?
Chapter 5

Yoga and Hypertension: A systematic Review

Tyagi A, Cohen M, 2014, Alternative Therapies 20(2); 32-59

Introduction

The single most important risk factor for cardiovascular diseases is hypertension (HPT) or continuously elevated blood pressure. Numerous studies have shown the association between cardiac autonomic function and hypertension. Lifestyle modification is the cornerstone of HPT, yet most recommendations currently focus on diet. Yoga is a spiritual path that may reduce blood pressure (BP) through reducing stress. However, despite reviews on yoga and cardiovascular diseases, diabetes, metabolic syndrome and anxiety that suggest yoga may reduce BP, no systematic review of all published studies has yet focused on yoga and HPT. This review with 120 studies suggests that yoga is an effective adjunct therapy for HPT.
Yoga and Hypertension: A Systematic Review

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ABSTRACT
Lifestyle modification is a cornerstone of hypertension (HPT) treatment, yet most recommendations currently focus on diet and exercise and do not consider stress reduction strategies. Yoga is a spiritual path that may reduce blood pressure (BP) through reducing stress, increasing parasympathetic activation, and altering baroreceptor sensitivity; however, despite reviews on yoga and cardiovascular disease, diabetes, metabolic syndrome, and anxiety that suggest yoga may reduce BP, no comprehensive review has yet focused on yoga and HPT. A systematic review of all published studies on yoga and HPT was performed revealing 39 cohort studies, 30 nonrandomized, controlled trials (NRCTs), 48 randomized, controlled trials (RCTs), and 3 case reports with durations ranging from 1 wk to 4 yr and involving a total of 6693 subjects. Most studies reported that yoga effectively reduced BP in both normotensive and hypertensive populations. These studies suggest that yoga is an effective adjunct therapy for HPT and worthy of inclusion in clinical guidelines, yet the great heterogeneity of yoga practices and the variable quality of the research makes it difficult to recommend any specific yoga practice for HPT. Future research needs to focus on high quality clinical trials along with studies on the mechanisms of action of different yoga practices. (Altern Ther Health Med. 2014;20(2):32-59.)

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Hypertension (HPT), which is defined as a persistently high blood pressure (BP) with systolic blood pressure (SBP) ≥ 140 and diastolic blood pressure (DBP) ≥ 90, is a major public health issue that is estimated to affect more than 1 billion people worldwide and account for 13% of deaths, 64 million disability-adjusted life years, and 7 million premature deaths per year. By the year 2025, it is estimated that approximately 1 in 3 adults aged over 20 years, or 1.56 billion people worldwide, will have HPT. The relationship between HPT and the risk of cardiovascular events, stroke, and kidney disease is continuous, consistent, and independent of other risk factors. Beginning at 115/75 mm Hg, each incremental rise of 20/10 mm Hg in BP substantially increases the risks of mortality and morbidity in cerebrovascular and cardiovascular disease (CVD), while treating raised BP is associated with a 35% to 49% reduction in the risk of stroke and a 16% reduction in the risk of myocardial infarction.

Pharmacological interventions for HPT are used routinely, yet the critical importance of nonpharmacological approaches and lifestyle modifications has continued to be recognized and recommended by expert panels on HPT. Lifestyle modifications may prevent HPT in prehypertensive individuals, serve as primary therapy in hypertensive participants before the start of drug therapy, and act as an adjunct to drug therapy for those already on medication. It is reported that lifestyle modification alone can reduce SBP from 3 mm Hg to 32 mm Hg and DBP from 2 mm Hg to 18 mm Hg. A 1982 meta-analysis of 37 studies on the nonpharmacological treatment of HPT found that nonpharmacological treatments such as yoga, weight reduction, and muscle relaxation produced stable reductions in BP over 3 to 12 months, suggesting that they are credible alternatives to pharmacotherapy.

A wealth of evidence now suggests that bidirectional interactions between the brain and peripheral tissues con-
Yoga and Hypertension: A Systematic Review

Chapter 5

Yoga as a Nonpharmacological Mind-Body Intervention

Yoga is an ancient Indian system for integrating mind and body that is claimed to bestow the practitioner with physical, mental, intellectual, and spiritual development. Yoga encompasses many different paths including karma yoga (service), bhakti yoga (devotion), jnana yoga (knowledge), and raja (8 limb path of patanjali). Hatha yoga, which is the most commonly practiced yoga in the West, emerged from raja yoga and includes a diverse range of mind-body practices such as meditation/relaxation techniques (dhyana), breathing practices (pranayama), and physical postures (asana).24

Researchers have postulated that yoga relaxation and breathing techniques may reduce BP by inducing slow rhythmic proprioceptive and efferent impulses, reducing peripheral adrenergic activity,39 and facilitating autonomic balance,32 which reduces chemoreceptor responses and enhances baroreflex sensitivity.36,37 Yoga breathing and relaxation practices are commonly performed as an integrated practice that also includes physical postures, and such practices have been used to reduce BP30 and positively affect other CVD risk factors, such as obesity,32 lipid profile,39 and glycemic control.34

In recent years, hatha yoga has become increasingly popular for dealing with stress, improving quality of life, treating a number of psychiatric and psychosomatic disorders, and improving psychological function.38 Yoga practices are now advocated for the symptomatic treatment of stress-induced disorders such as insomnia,39 anxiety,40 depression,40 and bronchial asthma.39,40 Yoga has also been found to improve physiological functions such as carbohydrate metabolism,40 lipid profile, and BP.

Reviews of Yoga and Clinical Conditions

Recent systematic reviews attest to the efficacy of yoga as a symptomatic treatment for several medical conditions, including (1) cancer,40 (2) arthritis,40 (3) anxiety,40,45 (4) depression,40,47 (5) back pain,40,49 (6) respiratory problems,40 and (7) menopausal symptoms.51 Many clinical studies and a number of systematic reviews also have been performed on yoga and cardiovascular disorders,40 (8) coronary heart disease,40 and cardiovascular risk factors such as diabetes.40,50

A number of general reviews have examined the effects of yoga-type interventions on BP. An exhaustive review and meta-analysis of 813 meditation studies, funded by the National Institutes of Health (NIH) and the National Center for Complementary and Alternative Medicine (NCCAM), noted that some meditation practices did produce significant changes in BP although the studies’ quality was generally poor and the interventions uncertain. A subgroup meta-analysis of 5 studies, totalling 201 healthy participants, found that yoga produced modest reductions in BP.52 Another comprehensive meta-analysis of 105 randomized, controlled trials (RCTs), involving 6085 hypertensive participants and a wide range of lifestyle interventions, found that relaxation techniques, including yoga, produced reductions in BP of around 4/3.1 mm Hg.53 A further meta-analysis of 17 RCTs on stress reduction approaches, involving 960 hypertensive participants, reported significant reductions in BP with meditation techniques.54 Another meta-analysis of 25 RCTs examining the benefits of relaxation therapies that involved 1198 participants, however, concluded there is only weak evidence that relaxation therapies produce meaningful BP reductions in hypertensive patients.55

Yoga, Cardiovascular Disease, and Metabolic Syndrome

A number of reviews that examined the use of yoga for people with heart disease and metabolic syndrome have included data on the effects of yoga on BP. A review of 13 studies on the efficacy of yoga in the primary and secondary prevention of ischemic heart disease suggested a definitive role for yoga; however, a subsequent systematic review of 6 RCTs of yoga for coronary risk factors concluded there was strong evidence for the benefits of yoga in the prevention and treatment of coronary heart disease in conjunction with normal medication, but that the evidence yoga alone led to reductions in BP was poor.56 A more comprehensive, systematic review of 70 studies, including 1 observational study, 26 uncontrolled trials, 21 nonrandomized controlled trials (NRCTs), and 22 RCTs, found beneficial effects for yoga for people with metabolic syndrome.57 A subset analysis of 37 studies that examined yogic interventions and BP found that yoga practice was helpful in producing short-term reductions in BP in individuals with metabolic syndrome.58 A further review of 32 studies from 1980 to 2007 found evidence for the efficacy of yoga in reducing BP as well as significant reductions in cholesterol, body weight, and blood glucose.58 Similarly, Innes and Vincent reviewed 25 published studies and found that yoga improved risk indices of non-insulin-dependent diabetes mellitus (NIDDM), including glucose tolerance, insulin sensitivity, lipid profiles, anthropometric measures, and BP.59

A recent analysis of 5 RCTs examining yoga, including 363 participants, revealed a prominent lowering of plasma glucose and lipid profile and short-term benefits with yoga practice for individuals with NIDDM, but the studies were...
generally of low quality and did not report a long-term follow-up. A more recent systematic review of 3 RCTs of 228 individuals with metabolic syndrome reported that meditation and yoga reduced disease symptoms and improved clinical indicators of the syndrome. More recently, 2 reviews attest to the benefits of yoga as a treatment for HPT. One reviewed the benefits of yoga for HPT in 19 studies published between the years 1972 and 2012, with 902 participants. This review reported that yoga was less costly than pharmacological therapies and, despite there being very few RCTs, suggested that yoga may serve as alternate to drugs in controlling HPT. Another review of 6 RCTs and 1 cohort study on yoga and HPT, published from 2006 to 2011, involved 714 normotensive and hypertensive participants and revealed that a diversity of yoga practices were consistently effective in reducing blood glucose, blood cholesterol, and body weight.  

While many clinical trials on yoga and HPT and multiple reviews of yoga for cardiovascular risk factors and metabolic syndrome have been published, the literature on yoga and HPT has not yet been the subject of a comprehensive systematic review. The following review attempts to document published studies on yoga and BP and explore the current evidence for specific practices and potential underlying mechanisms.

METHODS

The authors conducted a thorough primary search for published medical literature, using the terms yoga, yogic, shavasana, pranayama, breathing, or breath, with the acronym BP or HPT. Studies for this review were identified by a systematic search in the scientific databases Scopus, PubMed, PsycINFO, CINAHL, and ScienceDirect. Since yoga had its origins in the Indian subcontinent and a significant body of literature has been published in Indian medical journals, the databases IndMED and medind, which include bibliographical details from 75 of the major Indian medical journals, were also searched thoroughly. Similarly, an electronic version of Yoga Mimamsa, which includes published literature on yoga research dating back to 1920 and which was not listed in the above databases, was also searched as were the archives of the International Journal of Yoga.

All studies that evaluated BP as a primary or secondary outcome for yoga or yoga-type interventions were included. The search was not restricted by date or specific demographic or disease group and included all study types, including RCTs, NRCTs, cohort studies, and case studies. Studies were classified according to the type of intervention—yogic relaxation, slow breathing, integrated yoga practices, yoga, biofeedback, and use of the RespRATE device (InterCure Ltd, New York, NY, USA).

The authors included studies if they involved any specific component of yoga as well as all studies with a yoga-type intervention, such as slow, relaxed, focused breathing or yogic meditation like bhavana kriya, swadhyaya, garuda asana, raja yoga, om meditation, mantra meditation, salat yoga medit-
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Figure 1. Flowchart of Study Search and Included Studies

Studies identified in primary search: (N = 2,462)

Filtered and relevant studies extracted: (n = 440)

Final selected studies: 120, including:
- 39 cohort studies: 4 on relaxation, 6 on breathing, 23 on integrated yoga practice, 4 on biofeedback, 2 on RESPeRATE
- 30 NRCTs: 4 on relaxation, 5 on slow breathing, 15 on integrated yoga practice, 5 on biofeedback, 1 on RESPeRATE
- 48 RCTs: 3 on relaxation, 6 on slow breathing, 25 on integrated yoga practice, 6 on biofeedback, 8 on RESPeRATE
- 3 case reports

No mention of BP or HPT: 125
- Biochemistry, pharmacology, toxicology: 142
- Genetics and molecular biology: 184
- Veterinary and animal studies: 132
- Sleep studies: 73
- Neurology and psychiatry: 228
- Nonobtainable: 12
- Non-English: 187
- Not relevant for review: 40
- Not yoga-type intervention: 44
- Erratum: 12
- Report: 2
- BP not an outcome variable: 2
- Letter: 8
- Experimental study protocols: 3
- Laboratory studies: 21
- In press: 1

Figure 2. Summary of RCTs of Yoga and HPT

Studies are categorized according to (1) type of yogic intervention, (2) direction of result—change or no change in BP, (3) sample size—box height, (4) duration—box width, and (5) length of follow-up—shaded box width.

No. of RCTs = 48

RESPeRATE
RCTs: 8

Yoga and Biofeedback
RCTs: 6

Integrated Yoga Practice, HPT, and CVD
RCTs: 10

Practice
(RCTs: 15)

Slow Breathing
(RCTs: 6)

Yogic Relaxation
(RCTs: 3)

RCTs with no change in BP with yoga

RCTs with significant change in BP with yoga

Rama study with 4 y of follow-up; Patel et al. 1981; Patel et al. 1985

Box height – study sample

Box width – study duration
reductions in BP in untreated hypertensive patients as well as in those poorly controlled on medication (Table 1). A similar reduction in BP was reported in a 6-month study of 25 hypertensive patients practicing yogic relaxation, with BP reductions being maintained after 3 years in those individuals who continued with regular practice despite reduced use of antihypertensive medication. Yogic relaxation practices were reported to have both acute and long-term effects, with significant decreases in resting BP and heart rate (HR) reported in healthy young participants after a single 10-minute session of shavasana and with progressive BP reductions reported after 8 weeks of practice. 

Yogic Relaxation Controlled Trials

Table 2 shows reductions in BP with yogic relaxation that were reported in an adolescent population after 6 weeks of shavasana practice and in healthy participants after 3 months of practice of either shavasana or Transcendental Meditation as well as 3 weeks of practice of either hatha yoga or progressive muscle relaxation. Yoga relaxation practices have also been shown to reduce BP significantly in RCTs of 8 days involving hypertensive patients and of 8 months in women with menstrual irregularities, with BP remaining unchanged in control groups. A 6-month study suggests that relaxation practices may be particularly important in reducing BP, with the finding that normotensive elderly participants who practiced silver yoga, either with or without relaxation, had similar improvements in physical fitness compared with waiting-list controls, but that only the relaxation group experienced significant reductions in SBP. Similarly, a 4-week NRCT reported significant falls in BP in hypertensive patients when relaxation practices were combined with drug therapy (n = 50), although BP in healthy participants practicing relaxation (n = 10) remained unchanged.

Slow Breathing Cohort Studies

Several authors have reported significant reductions in resting BP in healthy participants after 4 weeks of practicing alternate nostril breathing (Table 3). An 8-week study also reported similar significant reductions in resting BP after a single 15-minute session of alternate nostril breathing (ANB) as well as progressive BP reductions with longer practice. Additionally, a recent 12-week study reported significant reductions in BP in normotensive participants studying mukh bhaatikra pranayama.

Not all studies on yoga breathing reported reductions in BP. One small study involving 6 healthy participants reported no change in BP after 6 months, despite reductions in pulse rate, fasting blood glucose, and blood lipids. Similarly, a 2-month study of normotensive participants (n = 6) and participants with chronic obstructive pulmonary disease (COPD) (n = 11) reported unchanged BP, together with an increase in low frequency (LF) and LF/high-frequency (HF) values, indicating sympathetic activation after 3 months of ANB.
### Table 2. Summary of Controlled Trials Reporting Changes in BP With Yogic Relaxation Practices

<table>
<thead>
<tr>
<th>Authors and Year</th>
<th>Design and Duration</th>
<th>Population</th>
<th>Intervention Details</th>
<th>Comparisons</th>
<th>BP Outcomes</th>
<th>Other Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagga et al, 1983&lt;sup&gt;37&lt;/sup&gt;</td>
<td>NRCT, 12 wk, 20 min/d</td>
<td>Healthy normotensive (n = 18)</td>
<td>TM (n = 6); shavasana (n = 6); controls relaxed, closed-eye sitting (n = 6)</td>
<td>Preintervention vs postintervention</td>
<td>4 of 8.94/4.6 mm Hg in SBP/DIA (P &lt; .01) after TM; 7.27/2.4 mm Hg (P &lt; .05) after shavasana compared with preintervention; no change in controls</td>
<td>4 of 9.97 BPM in HR (P &lt; .01) and of 7.9 BPM (P &lt; .05) after TM and shavasana, respectively; compared with preintervention</td>
</tr>
<tr>
<td>Chaudhary et al, 1988&lt;sup&gt;38&lt;/sup&gt;</td>
<td>NRCT, 4 wk</td>
<td>Hypertensive and normotensive (n = 60); hypertensive group (n = 50); healthy group (n = 10)</td>
<td>All experimental groups: yoga relaxation and pharmacological treatment (n = 30); controls: relaxation (n = 10)</td>
<td>Preintervention vs postintervention</td>
<td>4 of in BP 25.18/ 25.16 mm Hg in relaxation group compared with preintervention (P values not provided); no change in controls</td>
<td>4 of 3.22 in BPM and 4.13 in BPM in HR in yoga and PMR groups, respectively (P values not provided)</td>
</tr>
<tr>
<td>Cusumano et al, 1993&lt;sup&gt;39&lt;/sup&gt;</td>
<td>RCT, 3 wk, 3 sessions/wk of 80 min each</td>
<td>Healthy female normotensive (n = 95)</td>
<td>YP group (n = 45); PMR group (n = 45)</td>
<td>Preintervention vs postintervention and comparisons between the groups</td>
<td>4 of 3.49 mm Hg mean BP in yoga group and 4 of 2.17 mm Hg in mean BP in PMR group compared with preintervention (P values not provided); no significant differences between the interventions</td>
<td>4 of 3.22 in BPM and 4.13 in BPM in HR in yoga and PMR groups, respectively (P values not provided)</td>
</tr>
<tr>
<td>Irosta et al, 1995&lt;sup&gt;40&lt;/sup&gt;</td>
<td>RCT, 8 d</td>
<td>Hypertensive (n = 40)</td>
<td>Shavasana (n = 10); baroesta relaxation group (n = 10); PMR group (n = 10); controls: no intervention (n = 10)</td>
<td>Preintervention vs postintervention and comparisons between the groups</td>
<td>Significant reduction in BP (P &lt; .01) with all relaxation therapies compared with preintervention; no change in controls</td>
<td>Shavasana was most effective and prominent in reduction, followed by baroesta and PMR</td>
</tr>
<tr>
<td>Madamshen et al, 2004&lt;sup&gt;41&lt;/sup&gt;</td>
<td>NRCT, 6 wk</td>
<td>Healthy normotensive adolescents (n = 45)</td>
<td>Shavasana group (n = 17); control: no intervention (n = 17)</td>
<td>Preintervention vs postintervention</td>
<td>4 of 5/4 mm Hg in SBP/DIA (P &lt; .01)</td>
<td>4 of 5 BPM in HR (P &lt; .1)</td>
</tr>
<tr>
<td>Chen et al, 2008&lt;sup&gt;42&lt;/sup&gt;</td>
<td>NRCT, 24 wk</td>
<td>Elderly seniors &gt; 60 y (n = 176)</td>
<td>Silver yoga group with guided relaxation: 70 min each session for 3 d/wk (n = 53); silver yoga group without guided relaxation: 55 min/session for 3 d/wk (n = 53); waitlist controls (n = 66)</td>
<td>Preintervention vs postintervention</td>
<td>Significant reduction in SBP (P &lt; .05) in yoga group with guided relaxation compared with preintervention; no change in BP in yoga group without guided relaxation; no change in waistline controls</td>
<td>All physical fitness indicators (flexibility and motion) improved similarly in both experimental groups (P &lt; .05)</td>
</tr>
<tr>
<td>Moriki et al, 2012&lt;sup&gt;43&lt;/sup&gt;</td>
<td>BCT, 6 mo</td>
<td>Females with symptoms of menstrual irregularity (n = 150)</td>
<td>Yoga nidra group: 40 min/session for 5 d/wk (n = 75); controls: regular medication (n = 75)</td>
<td>Preintervention vs postintervention</td>
<td>4 of 2.98/2.22 mm Hg in SBP/DIA (P &lt; .01) after yoga nidra compared with preintervention; nonsignificant change in controls with medication</td>
<td>4 of 3.93 BPM in HR (P &lt; .01) and improvement in symptoms of menstrual irregularities after yoga nidra compared with preintervention; positive improvement in LE/HF ratio after yoga nidra</td>
</tr>
</tbody>
</table>

Abbreviations: TM = Transcendental Meditation; YP = yoga; PMR = progressive muscle relaxation; LF = low frequency; HF = high frequency.
### Table 3. Summary of Cohort Studies Reporting Changes in BP With Slow Breathing Practices

<table>
<thead>
<tr>
<th>Authors and Year</th>
<th>Design and Duration</th>
<th>Population</th>
<th>Intervention</th>
<th>Comparisons</th>
<th>BP Outcomes</th>
<th>Other Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Udapa et al., 1975*</td>
<td>Cohort, 6 mo</td>
<td>Normotensive (n = 6)</td>
<td>Yoga breathing, uttana bhedana</td>
<td>Preintervention vs postintervention</td>
<td>No change in resting BP</td>
<td>↑ of 2.4 kg in body weight, ↓ in fasting glucose, total serum lipid, and serum protein (P values not provided)</td>
</tr>
<tr>
<td>Bharagava et al., 1988*</td>
<td>Cohort, 4 wk</td>
<td>Normotensive (n = 10)</td>
<td>ANB for 30 min/session</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 8.8/5.16 mm Hg in resting SBP/DiP (P &lt; 0.05) compared with preintervention</td>
<td>No change in resting HR</td>
</tr>
<tr>
<td>Sivarastu et al., 2005*</td>
<td>Cohort, 4 wk</td>
<td>Normotensive (n = 40)</td>
<td>ANB for 15 min/session</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 6.4 mm Hg and 3.6 mm Hg (P &lt; 0.001 and P &lt; 0.01) in SBP in males and females compared with preintervention</td>
<td>↓ of 12.55 and 11.7 BPM in HR males and females, (P &lt; 0.001 and P &lt; 0.001), respectively, after 8 wk</td>
</tr>
<tr>
<td>Upadhyay et al., 2008*</td>
<td>Cohort, 4 wk</td>
<td>Normotensive (n = 36)</td>
<td>ANB for 15 min/session</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 4.16 mm Hg in DBP (P &lt; 0.001) compared with preintervention</td>
<td>↓ of 3 BPM in pulse rate (P &lt; 0.001) and improvement in respiratory variables (P &lt; 0.001)</td>
</tr>
<tr>
<td>Veerabhadrappa et al., 2011**</td>
<td>Cohort, 3 mo</td>
<td>Normotensive males (n = 50)</td>
<td>Mukh bhastrika</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 428 mm Hg in supine mean BP (P &lt; 0.001), and ↓ of 232 mm Hg in standing mean BP (P &lt; 0.01) compared with preintervention</td>
<td>↓ of 13.4 BPM (P &lt; 0.001) in HR</td>
</tr>
<tr>
<td>Ijai et al., 2011**</td>
<td>Cohort, 3 mo</td>
<td>Normotensive (n = 11), healthy normotensive (n = 6)</td>
<td>ANB with extended respiration (60:60) for 30 min in each session for 5 d/wk</td>
<td>Preintervention vs postintervention</td>
<td>No change in BP in normotensive controls (P &lt; 0.01)</td>
<td>Non-significant ↑ in LF and MS/HR values in both groups, indicating sympathetic activation</td>
</tr>
</tbody>
</table>

Abbreviations: COPD = chronic obstructive pulmonary disease; ANB = alternate nostril breathing; BPM = beats per minute.

### Slow Breathing Controlled Trials

The above cohort studies are supported by a series of controlled clinical studies (Table 4). Two separate RCTs with durations of 3 months reported reductions in SBP after regular slow breathing practice in adolescents with borderline HBP.11,12 Reductions in SBP were also observed with slow breathing in a placebo-controlled trial of hypertensive patients who were randomly assigned either to listen to music, read a book, or perform breathing that was synchronized to slow musical rhythms at 4.6 breaths/minute (BPM).13 Three months of either slow breathing at 6 BPM or fast breathing at 60 BPM was also found to reduce BP in another RCT involving hypertensive patients, with BP reductions being more prominent after slow breathing.65

Additionally, 3 NRCTs, 1 lasting 6 weeks and 2 lasting 8 weeks, reported a reduction in BP in normotensive participants.66-68 BP was reported to be reduced after a single session of either right nostril breathing (RNBr) or left nostril breathing (LNB), with a pronounced drop reported after 8 weeks of practice.69 Significant falls in BP were also reported with ANB after 8 weeks when compared with sun salutation69 and after 6 weeks when compared with no intervention.70 A more recent 3-month NRCT reported significant reductions in BP with yogic breathing maneuvers comprising uttana bhastrika, anulom vilom, and slow-focused meditation practices.71 Furthermore, a small study of 30 participants reported significant reductions in DBP after 3 weeks of slow breathing practice (samvriti pranayama) and a nonsignificant rise in DBP, with a significant rise in HR with fast-paced bhastrika breathing.72 However, 2 RCTs of 3 months reported no change in BP in normotensive adolescents practicing various different types of slow pranayamic breathing65 and in diabetic participants practicing slow diaphragmatic breathing, despite significant improvement in CVD risk factors.67

### Integrated Yoga Practice Cohort Studies

Significant BP and HR reductions have been consistently observed with integrated yoga practices (Table 5). Cohort studies involving healthy volunteers performing yoga postures and breathing practices have reported reductions in BP and HR after 2 weeks,66 2 months,66 3 months,66 and 6 months.73 Significant reductions in BP with breathing and postural practices were also observed in 13 hypertensive participants after 4 weeks66 and in 10 hypertensive participants and 17 hypertensive participants with CAD after 5 weeks but not in participants with CAD alone.66 In contrast
<table>
<thead>
<tr>
<th>Authors and Year</th>
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<th>Intervention</th>
<th>Comparisons</th>
<th>BP Outcomes</th>
<th>Other Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uluppu et al., 2003&lt;sup&gt;17&lt;/sup&gt;</td>
<td>RCT, 3 mo</td>
<td>Normotensive adolescents (&lt;n = 24&gt;)</td>
<td>Pranayama group: ANB, multi-bhavikriti, pranayama, pranina, (n = 12); controls: no intervention (n = 12)</td>
<td>Preintervention vs postintervention</td>
<td>No change in BP in either group</td>
<td>4 of 9.16 BPM in HR (P &lt; .01) in pranayama group</td>
</tr>
<tr>
<td>Manavwan et al., 2005&lt;sup&gt;18&lt;/sup&gt;</td>
<td>NRCT, 3 wk</td>
<td>Normotensive adolescents (&lt;n = 30&gt;)</td>
<td>Slow breathing group with breath hold; savari pranayama, 2:1:2:1 (n = 15); fast breathing group; bhavikriti (n = 15)</td>
<td>Preintervention vs postintervention</td>
<td>4 of 2.93 mm Hg in DBP (P &lt; .05) with slow breathing compared with preintervention; nonsignificant increase in DBP with fast breathing, compared with preintervention</td>
<td>Non-significant decrease in HR with slow breathing; 1 of 6.44 BPM in HR (P &lt; .05) with fast breathing</td>
</tr>
<tr>
<td>Jain et al., 2005&lt;sup&gt;19&lt;/sup&gt;</td>
<td>NRCT, 8 wk</td>
<td>Normotensive adolescents (&lt;n = 40&gt;)</td>
<td>RNB group (n = 20) and LNB group (n = 20); each with 15-min sessions/d for 8 wk</td>
<td>Preintervention vs postintervention</td>
<td>4 of 6.55 mm Hg in SBP/DBP (P &lt; .001)/P &lt; .05) in males and 5.53 mm Hg in DBP (P &lt; .01) in females with RNB, compared with preintervention; 4 of 9.77 mm Hg in SBP/DBP (P &lt; .001)/P &lt; .05) in males and 8.55 mm Hg (P &lt; .01)/P &lt; .05) in females with LNB compared with preintervention</td>
<td>4 of 12 BPM and 3 BPM in HR (P &lt; .01) and (P &lt; .05) in males and females, respectively, after RNB, 4 of 16 BPM and 13 BPM in HR (P &lt; .001) and (P &lt; .05) in males and females, respectively, after LNB</td>
</tr>
<tr>
<td>Barnes et al., 2008&lt;sup&gt;20&lt;/sup&gt;</td>
<td>RCT, 3 mo</td>
<td>Borderline hypertensive adolescents (&lt;n = 66&gt;)</td>
<td>BAM group: slow, deep, relaxed, and focused dia-phragmatic breathing (n = 20); HEC: group education on BP, weight reduction, and diet—salt and fat reduction (n = 45)</td>
<td>Preintervention vs postintervention</td>
<td>4 of 4.7 mm Hg in SBP (P &lt; .05) during school and 4.8 mm Hg (P &lt; .05) during night in BAM group compared to preintervention; no statistically significant change in HEC</td>
<td>4 of 6.7 BPM in HR (P &lt; .02) during school and 2.2 BPM (P &lt; .05) at night with BAM</td>
</tr>
<tr>
<td>Mourya et al., 2009&lt;sup&gt;21&lt;/sup&gt;</td>
<td>RCT, 3 mo</td>
<td>Hypertensive (&lt;n = 60&gt;)</td>
<td>Slow breathing group: 5-6 BPM; occlusion of either nostril alternatively (n = 33); fast breathing group: short and quick 60 BPM for 1 min followed by 3-min pause (n = 20); controls: no intervention (n = 20)</td>
<td>Preintervention vs postintervention</td>
<td>Significant fall in SBP/DBP with slow breathing (P &lt; .0001)/P &lt; .0001 and fast breathing (P &lt; .0001)(P &lt; .0001)</td>
<td>4 of 7.4 mm Hg in office SBP (P &lt; .05); 4 of 7.5 mm Hg in 24-h ambulatory SBP (P &lt; .0001) at follow-up compared with preintervention; no change for music relaxation and book reading, reduction in slow breathing group (P &lt; .001) compared with slow music and book reading</td>
</tr>
<tr>
<td>Modesti et al., 2010&lt;sup&gt;22&lt;/sup&gt;</td>
<td>RCT, placebo-controlled, 6 mo, with 6 mo of follow-up</td>
<td>Hypertensive (&lt;n = 40&gt;)</td>
<td>Slow sleeping breathing: synchronized with music up to 4-6 BPM as per Buziokyo method, 90 min and 20 min abdominal breathing with 1:2 inspiration and expiration ratio (n = 29); slow music to relax group (n = 28); controls: reading book or magazine (n = 31)</td>
<td>Preintervention vs postintervention and comparison between groups</td>
<td>4 of 5.51/5.05 mm Hg in testing SBP/DBP (P &lt; .05)/(P &lt; .05) with ANB compared with preintervention; nonsignificant change with sun salutation</td>
<td>4 of 4.73 BPM in HR (P &lt; .05) with ANB and nonsignificant change with sun salutation</td>
</tr>
</tbody>
</table>
### Table 4. (continued)

<table>
<thead>
<tr>
<th>Authors and Year</th>
<th>Design and Duration</th>
<th>Population</th>
<th>Intervention</th>
<th>Comparisons</th>
<th>BP Outcomes</th>
<th>Other Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singh et al., 2011</td>
<td>NRCT, 6 wk</td>
<td>Normotensive (n=30)</td>
<td>AEF group: 36 min/day (n=20); controls: no intervention (n=15)</td>
<td>Pretreatment vs postintervention</td>
<td>↓ of 4.94 mm Hg in SBP (P&lt;.05), with ANB compared with pretreatment; no change in controls</td>
<td>↓ of 10.1 BPM in HR (P&lt;.01) with ANB</td>
</tr>
<tr>
<td>Malik et al., 2011</td>
<td>NRCT, 3 mo</td>
<td>Normotensive (n=150)</td>
<td>Yoga breathing group: sariyayi, bhatrika, hamsa chanting, and shavasana meditation (n=100); controls: no intervention (n=50)</td>
<td>Pretreatment vs postintervention</td>
<td>↓ of 8.6 mm Hg in SBP (P&lt;.0001) after yoga breathing compared with pretreatment; no change in controls</td>
<td>↓ of 11.4 BPM in HR (P&lt;.001) after yoga breathing; ↓ of 56.1/min in PEFR (P&lt;.001) for experimental group</td>
</tr>
<tr>
<td>Gregoski et al., 2011</td>
<td>RCT, 3 mo</td>
<td>Borderline hypertensive adolescents (n=166)</td>
<td>BAM group: slow, deep, relaxed, and focused diaphragmatic breathing (n=53); LST group (n=69); HEC: controls; education on BP, weight reduction, and diet—salt and fat reduction (n=44)</td>
<td>Comparison between groups</td>
<td>↓ of 3.1 mm Hg in SBP with BAM (P&lt;.01) compared with LST and (P&lt;.02), compared with HEC; ↓ of 2 mm Hg in DBP with BAM (P&lt;.003) compared with LST and 1.7 mm Hg (nonsignificant) compared with HEC</td>
<td>Reduction of 3.2 BPM in HR with BAM (P&lt;.03) compared with LST</td>
</tr>
<tr>
<td>Hegde et al., 2012</td>
<td>RCT, 3 mo with follow-up</td>
<td>Type 2 diabetes (n=123)</td>
<td>DB group: slow, deep, mindful, relaxed breathing, either in supine or sitting position for 20 min/session 2 x/4 (n=60); controls: standard care including information about diet and exercise (n=63)</td>
<td>Pretreatment vs postintervention and comparison between groups</td>
<td>Nonsignificant change in BP with DB at follow-up compared with pretreatment; no significant difference between the groups</td>
<td>Improvement in glycemic index—fasting and postprandial (P&lt;.001 and P&lt;.007, respectively) at follow-up with DB compared with pretreatment; improvement in BMI (P&lt;.001) and WHR (P&lt;.001) with DB compared with control at follow-up</td>
</tr>
</tbody>
</table>

Abbreviations: ANB = alternate nostril breathing; RNB = right nostril breathing; LNB = left nostril breathing; BAM = breath awareness meditation; HEC = health education control; EPM = breaths or beats per minute; LST = lifestyle training; DB = diaphragmatic breathing; PEFR = peak expiratory flow rate, WHR = waist-hip ratio.

In those findings, 4 studies involving normotensive participants reported no change in BP.

Of these, 2 small studies of 8 people reported no change in BP after 2 weeks of practicing a single yoga posture (shoulder stand posture) and 4 weeks of practicing a defined sequence of postures, breathing, and chanting (shanti kriya). Similarly, no significant change in BP was reported in a 6-week study of 64 medical students undertaking a single weekly yoga session and regular home practice or in an 11-week study of 17 riddle and elderly yoga practitioners undertaking intense yoga training. Additionally, BP remained unchanged despite improvements in heart rate variability (HRV) and mood in a further 4-week study of 6 participants awaiting organ transplants.

#### Integrated Yoga Practice Controlled Studies

Controlled trials of integrated yoga interventions were consistent with the above cohort studies (Table 6). Differential effects on BP with different yoga practices were observed in a 6-week study of healthy participants that found significant falls in DBP with ashtanga yoga compared with a lesser, nonsignificant reduction in BP with hatha yoga. Two controlled trials involving healthy normotensive people reported larger reductions in BP after 10 weeks and 6 weeks compared with controls receiving no intervention. A recent controlled trial also reported significant reductions in BP with salabhasana in hypertensive participants with or without type 2 diabetes (n=67) compared with participants with standard medical treatment (n=62), with the reductions being more prominent among the diabetic participants. A further 3-month RCT of 30 healthy soldiers reported reductions in BP for those adhering to a hatha yoga lifestyle, including dietary measures compared with no change in BP for those undertaking only aerobic exercise. Reductions in BP with integrated yoga practices were also reported in a 6-month RCT of depressed participants practicing kundalini yoga, compared with participants taking antidepressant medication. A 2-month RCT of gentle iyengar yoga in postmenopausal women with restless leg syndrome also found reductions in BP compared with a control group receiving instruction on general awareness through personal interaction and visual aids.

Similarly, BP reductions were reported in participants with rheumatoid arthritis after 40 days of yoga compared...
Table 5. Summary of Cohort Studies Reporting Changes in BP With Integrated Yoga Practices

<table>
<thead>
<tr>
<th>Authors and Year</th>
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<th>Population</th>
<th>Intervention</th>
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<th>BP Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>LakshmiKrithika et al, 1999*</td>
<td>Cohort, 5 wk</td>
<td>Hypertensive and CAD patients (n=44); hypertensive group (n=10); CAD + hypertensive group (n=17)</td>
<td>Yoga, postural and relaxation</td>
<td>Preintervention vs postintervention                     4 of 9.7/8.8 mm Hg in SBP/DBP (P&lt;.05/P&lt;.01) in hypertensive group and 4 of 12.9/8.47 mm Hg (P&lt;.05/P&lt;.01) in hypertensive + CAD group compared with preintervention; no change in CAD patients</td>
<td>4 of 5.93 BPM in pulse rate (P&lt;.05)</td>
</tr>
<tr>
<td>Anantharaman et al, 1984*</td>
<td>Cohort, 3 mo</td>
<td>Normotensive (n=17)</td>
<td>Integrated yoga postural practices coordinated with parasympnic breathing movement</td>
<td>Preintervention vs postintervention                4 of 3.2/4.4 mm Hg in SBP/DBP (P&lt;.05/P&lt;.05) with yoga intervention compared with preintervention</td>
<td>4 of 5.93 BPM in pulse rate (P&lt;.05)</td>
</tr>
<tr>
<td>Sattanayayum et al, 1992**</td>
<td>Cohort, 30 d</td>
<td>Normotensive (n=8)</td>
<td>Shantii kriya: yogaic postures incorporated with breathing, meditation, chanting, and relaxation</td>
<td>Preintervention vs postintervention</td>
<td>No significant change in BP</td>
</tr>
<tr>
<td>Konar et al, 2000***</td>
<td>Cohort, 2 wk</td>
<td>Normotensive (n=8)</td>
<td>Surrangasa (shoulder stand posture)</td>
<td>Preintervention vs postintervention</td>
<td>No significant change in BP</td>
</tr>
<tr>
<td>Madhunandan et al, 2004*</td>
<td>Cohort, 2 mo</td>
<td>Normotensive (n=21)</td>
<td>Yoga postures and yoga breathing</td>
<td>Preintervention vs postintervention</td>
<td>4 of 2.98/6.19 mm Hg in resting SBP/DBP (P&lt;.01/P&lt;.01) with yoga intervention compared with preintervention; 4 of 5.95 mm Hg in MAP (P&lt;.001)</td>
</tr>
<tr>
<td>Vijayalakshmi et al, 2004*</td>
<td>Cohort, 4 wk</td>
<td>Hypertensive (n=13)</td>
<td>Yoga postures and yoga breathing</td>
<td>Preintervention vs postintervention</td>
<td>4 of 2.11/1.93 mm Hg in SBP/DBP (P&lt;.01/P&lt;.01) and 4 of 12.40 mm Hg in MAP (P&lt;.001) after yoga intervention compared with preintervention</td>
</tr>
<tr>
<td>Ramos-Liménez et al, 2009**</td>
<td>Cohort, 11 wk</td>
<td>Normotensive female yoga practitioners practicing yogic exercises of low aerobic intensity for ≥ 3 y (n=50)</td>
<td>Intensive hatha yoga program with dynamic stretching, postures, breathing, and meditation, 90 min/session 3 days</td>
<td>Preintervention vs postintervention</td>
<td>No change in BP</td>
</tr>
<tr>
<td>Herer et al, 2010**</td>
<td>Cohort, 6 mo</td>
<td>Normotensive (n=50)</td>
<td>Yoga: stretching, prayers, asana pranayama, meditation, relaxation</td>
<td>Preintervention vs postintervention</td>
<td>4 of 8.6 mm Hg in SBP/DBP (P&lt;.001/P&lt;.001) with yoga intervention compared with preintervention</td>
</tr>
<tr>
<td>Askad et al, 2011*</td>
<td>Cohort, 2 wk</td>
<td>Normotensive (n=50)</td>
<td>Yoga: pranayama and meditation</td>
<td>Preintervention vs postintervention</td>
<td>4 of 3.8/3.98 mm Hg in SBP/DBP (P&lt;.001/P&lt;.001) postintervention compared with preintervention</td>
</tr>
<tr>
<td>Dalgoff Kasprzak et al, 2012**</td>
<td>Cohort, 4 wk</td>
<td>Patients awaiting organ transplant (n=6)</td>
<td>Laughing yoga: 7 sessions of 20 min with breathing and stretching and laughter exercise with rhythmic clapping and guided meditation</td>
<td>Preintervention vs postintervention</td>
<td>No change in BP with yoga postintervention</td>
</tr>
</tbody>
</table>

Tyagi—Yoga and Hypertension
Chapter 5
Yoga and Hypertension: A Systematic Review

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Table 5. (continued)

<table>
<thead>
<tr>
<th>Authors and Year</th>
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<tbody>
<tr>
<td>Parsi et al., 2012</td>
<td>Cohort, 6 wk</td>
<td>Normotensive (n = 64)</td>
<td>Yoga asanas, pranayama, and meditation 1 h/wk for 60 min and regular 10-min practice of meditation at home</td>
<td>Preintervention vs postintervention</td>
<td>No change in BP postyoga intervention compared with preintervention</td>
<td>T in HR (P &lt; .05), CO (P &lt; .001), SV (P &lt; .01), and CO (P &lt; .01) and 4 in BII (P &lt; .01) with yoga postintervention compared with preintervention</td>
</tr>
</tbody>
</table>

Abbreviations: CAD = coronary artery disease; MAP = mean arterial pressure; BPM = beats per minute; VO2max = maximal oxygen uptake; HRV = heart rate variability; CO = cardiac output; SV = stroke volume; BII = interbeat interval.

with waitlist controls and in osteoarthritis participants after 3 months of follow-up preceded by 15 days of yoga compared with therapeutic exercise. Additionally, a 10-week RCT reported reductions in BP in an elderly group practicing yoga in weekly sessions with home practice compared with a control group engaged in physical entertainment, with more prominent reductions observed in a subgroup attending class and regularly practicing at home.

Controlled studies in hypertensive individuals suggest that reductions in BP with yoga practice may be augmented by other lifestyle modification, such as physical activity and dietary modifications. A recent 9-month NRCT reported improvement in HRV and falls in BP in hypertensive and normotensive people practicing yoga, with reductions becoming statistically significant only in those practicing yoga together with physical exercise. Similarly, an 8-week RCT that examined the effects of yoga, brisk walking, and salt reduction in hypertensive participants found that significant reductions in BP occurred with yoga as well as with brisk walking and salt reduction compared with controls receiving no intervention.

A number of studies have compared yoga groups to no-intervention or active-intervention controls, and 1 study reported reductions in BP with a yoga intervention similar to a head-tilt active control group. Not all controlled trials reported BP reductions. No change in BP with yoga was reported in normotensive participants after 24 months of yogic breathing and relaxation or after 8 weeks of Iyengar yogic techniques using various props compared with control participants maintaining their regular lifestyles.

Seven RCTs reported no change in BP in yoga groups compared with no-intervention or active controls, despite other significant benefits. A nonsignificant reduction in BP was reported in 3 controlled trials in sedentary populations: (1) after 6 weeks of gentle yoga in sedentary, normotensive, elderly participants, despite significant reductions in HR; (2) after 8 weeks of Bikram yoga in sedentary, normotensive young adults, despite significant improvement in body flexibility; and (3) after 8 months of Ashtanga yoga in sedentary, normotensive, premenopausal women, despite improvements in muscle strength. Similarly, a nonsignificant change in BP, despite significant reductions in HR, was reported in a 10-week controlled trial of yoga and relaxation for people with mild to moderate stress. Nonsignificant changes in BP, despite significant improvements in psychological stress, were also reported in a 12-week study of integrated yoga in medical students under examination stress and in a 16-week study of kundalini yoga in a population under mild stress. A further RCT involving mild hypertensive patients reported no reduction in BP after 1 year of yoga relaxation or nonspecific counseling.

Integrated Yoga Practice for Cardiac Risk Factors

A significant body of laboratory and clinical evidence suggests that yoga balances autonomic responses and improves BP and other CVD variables in both healthy and hypertensive participants, with reductions in body weight, body fat mass, and BMI, hypercholesterolemia, hyperglycaemia, and hyperglycaemia.

Cohort Studies on Integrated Yoga Practice for Cardiac Risk Factors

Reductions in BP, HR, and body weight were reported in a study of 30 healthy sports teachers after 3 months of residential yoga training, and reductions in BP and body fat were reported in participants over age 65 after 4 weeks of silver yoga practice involving gentle yoga movements and postures together with rhythmic breathing and relaxation (Table 7). More recently, a reduction in BP was reported in 2 studies, each with 50 healthy volunteers, 1 after 6 weeks with significant improvement in body fat percentage and weight and 1 after 6 months with significant reduction in HR and body weight.

In addition to improving BP and body weight, integrated yoga practices were found to improve blood lipids in a study of normotensive and hypertensive participants and improvements in BP and lipids along with glycemic index were reported in studies of healthy normotensive participants and in a population with metabolic abnormalities. Improvements in BP and better glycemic control were also reported in diabetic individuals after 40 days of yoga practice. Cohort studies have also reported reductions in use of antihypertensive medications together with improvements in BP, lipid profile, and glycemic index after 3 months and...
## Table 6. Summary of Controlled Studies Reporting Changes in BP With Integrated Yoga Practices

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<tr>
<th>Authors and Year</th>
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<tr>
<td>Haber, 1983&lt;sup&gt;10&lt;/sup&gt;</td>
<td>RCT, 10 wk</td>
<td>Healthy elderly population (white and black) from 2 community centers (n = 106)</td>
<td>Yoga group: gentle yoga 2 x wk with in-class and at-home practice (n = 63); control group: either film series or art activity (n = 43)</td>
<td>Preintervention vs postintervention and comparison between the groups</td>
<td>↓ of 12/7 mm Hg in SBP/DBP in the community with white elders practicing yoga on regular basis, with higher income and educational levels and reported good health on self-rated scale; ↓ of 7/4 mm Hg in the community with black elders practicing yoga irregularly, with lower educational and income levels and reported fair health on self-rated scale (P-values not provided); significant reduction in BP of white elders compared with control (P &lt; .05); nonsignificant difference in black elders compared with controls</td>
<td>Improved psychological well-being in white elderly community compared with black elderly community (P &lt; .05)</td>
</tr>
<tr>
<td>Devi et al, 1990&lt;sup&gt;10&lt;/sup&gt;</td>
<td>RCT, 6 mo</td>
<td>Depressive (n = 180)</td>
<td>Kundalini yoga group- asana, pranayama, and concentration on chakras, 60 min/d (n = 40); group using usual antidepressant drugs (n = 40)</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 8/5 mm Hg in SBP/DBP (P &lt; .001) with yoga compared with pretreatment; ↓ of 11.9 mm Hg in SBP/DBP (P &lt; .001) (P &lt; .001) with drug therapy compared with pretreatment</td>
<td>↓ in pulse 13 BPM (P &lt; .001) and 14 BPM (P &lt; .001) with yoga and drugs, respectively</td>
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<tr>
<td>Van Montfrans et al, 1990&lt;sup&gt;10&lt;/sup&gt;</td>
<td>RCT, placebo control, 8 wk, with 12 mo of follow-up</td>
<td>Hypertensive (n = 35)</td>
<td>Yoga group: muscle relaxation, yoga exercise, and stress management (n = 10); control group: sit and relax 2 x/d (n = 17)</td>
<td>Preintervention vs postintervention at the end of follow-up period</td>
<td>No change in BP in both groups</td>
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<tr>
<td>Raju et al, 1994&lt;sup&gt;10&lt;/sup&gt;</td>
<td>NRCT, 24 mo</td>
<td>Normotensive (n = 28)</td>
<td>Yoga group: breathing and relaxation with physical workouts (n = 14); control group: physical workouts (n = 14)</td>
<td>Preintervention vs postintervention</td>
<td>No significant change in resting BP in both groups compared with pretreatment</td>
<td>No change in resting HR</td>
</tr>
<tr>
<td>Bowman et al, 1997&lt;sup&gt;10&lt;/sup&gt;</td>
<td>RCT, 6 wk</td>
<td>Sédentary normotensive elderly &gt; 62 yr (n = 26)</td>
<td>Yoga group: stretching exercises and breathing with 20 min relaxation (n = 12); aerobic exercise group: 40 min of warm-up, workload to increase HR, and warm-down training (n = 14)</td>
<td>Preintervention vs postintervention</td>
<td>No significant change in BP in either group; reduction in BP prominent in aerobic group compared with yoga group</td>
<td>↓ of 8 BPM in HR (P &lt; .05) in yoga group compared with pretreatment; no significant change in HR in aerobic group</td>
</tr>
<tr>
<td>Selvanurty et al, 1998&lt;sup&gt;10&lt;/sup&gt;</td>
<td>NRCT, 3 wk</td>
<td>Hypertensive (n = 30)</td>
<td>Yoga group: specific yoga posture of head up or down lift for 30 min/d (n = 30); control group: 70° head lift for 30 min/d (n = 10)</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 29/17 mm Hg in SBP/DBP (P &lt; .001) in yoga group and of 21/1 bmi Hg in tilt group (P &lt; .001) postintervention compared with pretreatment</td>
<td>↓ of 7 BPM in HR (P &lt; .01) in yoga group and 9 BPM in tilt in both groups</td>
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Tyagi—Yoga and Hypertension
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<tr>
<td>Ray et al., 2000&lt;sup&gt;18&lt;/sup&gt;</td>
<td>RCT cross-over trial, 10 mo</td>
<td>Normotensive (n = 54)</td>
<td>Comprehensive yoga intervention group: asanas, pranayama, meditation in 60-min sessions 2 x/d (n = 15); aerobic exercise group: body flexibility, slow running, games in 60-min sessions 2 x/d (n = 15)</td>
<td>Preintervention vs postintervention</td>
<td>4 of 16.17 mm Hg and 11.2 mm Hg in SBP (P &lt; .001) for males and females, respectively, of yoga group compared with preintervention; 4 of 8.75 mm Hg and 6.4 mm Hg in SBP (P &lt; .001 and P &lt; .05) in males and females, respectively, of waitlist control group compared with preintervention; nonsignificant change in DBP in both groups</td>
<td>Significant reduction in HR in both groups</td>
</tr>
<tr>
<td>Hari-Asath et al., 2004&lt;sup&gt;19&lt;/sup&gt;</td>
<td>RCT, 3 mo</td>
<td>Normotensive (n = 38)</td>
<td>Integrated yoga group: asanas, pranayama, meditation in 60-min sessions 2 x/d (n = 15); aerobic exercise group: body flexibility, slow running, games in 60-min sessions 2 x/d (n = 15)</td>
<td>Preintervention vs postintervention</td>
<td>4 of 6.2/9.6 mm Hg in SDBP/DPP (P &lt; .001) in yoga group compared with preintervention; no change in BP of aerobic group</td>
<td>No significant change in HR</td>
</tr>
<tr>
<td>Cowan et al., 2005&lt;sup&gt;20&lt;/sup&gt;</td>
<td>NECT, 6 wk</td>
<td>Normotensive (n = 20)</td>
<td>Ashtanga yoga group: asanas, pranayama, breathing, and warm-up with sun salutation (n = 15); hatha yoga group: asanas, relaxation, breathing, and warm-up of sun salutation (n = 15); yoga sequences were performed for 75 min 2 x/wk</td>
<td>Preintervention vs postintervention</td>
<td>Significant reduction in DBP with both yoga styles but prominent reductions with ashtanga yoga</td>
<td>Improvement in upper-body and trunk dynamic muscular strength with yoga training</td>
</tr>
<tr>
<td>Granatth et al., 2006&lt;sup&gt;21&lt;/sup&gt;</td>
<td>RCT, 16 wk</td>
<td>Normotensive with mild stress (n = 33)</td>
<td>Kundalini yoga group balancing body movements, breathing, meditation, and diet awareness (n = 16); CBT group: psychoeducation management techniques for stress, anger, and mindful relaxation (n = 17)</td>
<td>Preintervention vs postintervention</td>
<td>Nonsignificant change in BP in both groups</td>
<td>Significant reduction in HR (P &lt; .07) in yoga group compared with preintervention; improvement in psychological markers of stress in both groups, compared with their respective preintervention values</td>
</tr>
<tr>
<td>Smith et al., 2007&lt;sup&gt;22&lt;/sup&gt;</td>
<td>RCT, 10 wk, with 6 wk follow-up</td>
<td>Normotensive with mild stress (n = 111)</td>
<td>Yoga intervention group: asanas, pranayama, relaxation, and meditation (n = 68); PAME group: audiotape with music in 10- to 15-min sessions/wk (n = 63)</td>
<td>Preintervention vs postintervention</td>
<td>No change in BP with either intervention</td>
<td>Significant improvement in stress and anxiety scores in both groups, with magnitudes being prominent with yoga; improvement was maintained after follow-up periods of 6 wk.</td>
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### Table 6. (continued)

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<thead>
<tr>
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<tr>
<td>Madamunna et al., 2009&lt;sup&gt;98&lt;/sup&gt;</td>
<td>RCT, 6 wk</td>
<td>Normotensive (n=46)</td>
<td>Yoga intervention: group: asana, pranayama, and relaxation (n = 23); no intervention control (n = 23)</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 12 mm Hg and 7 mm Hg in DBP (P &lt; .02/P &lt; .03) in males and females, respectively, with yoga postintervention compared with preintervention; no change in controls</td>
<td>No change in EBL; improvement in muscle strength and endurance (P &lt; .05)</td>
</tr>
<tr>
<td>Niranjan et al., 2009&lt;sup&gt;13&lt;/sup&gt;</td>
<td>NRCT, 9 mo</td>
<td>Hypertensive and normotensive (n=78)</td>
<td>Yoga group: postures, breathing, and relaxation (n=16); exercise group: warming, cycling/treadmill (n=16); yoga + exercise group (n=15); normotensive control group (n=31)</td>
<td>Preintervention vs postintervention and comparison between groups</td>
<td>↓ of 7.5/6.12 mm Hg in SBP/DBP (P &lt; .05/P &lt; .05) in exercise group and ↓ of 7.8/6.94 mm Hg (P &lt; .05/P &lt; .05) in exercise group and yoga + exercise group postintervention compared with preintervention; nonsignificant drop in yoga group</td>
<td>Improved HRV in exercise group (P &lt; .001) and yoga + exercise (P &lt; .001) group; nonsignificant change in yoga group compared with preintervention</td>
</tr>
<tr>
<td>Saptharishi et al., 2009&lt;sup&gt;11&lt;/sup&gt;</td>
<td>RCT, 8 wk</td>
<td>Hypertensive (n=113)</td>
<td>Yoga group: 30.45 min/d for 6 d; (n=27); brisk walk group: 50-60 min, 4.9 d/wk (n=28); all reduction group: half previous intake (n=29); no-intervention control group (n=30)</td>
<td>Preintervention vs postintervention and comparison between groups</td>
<td>↓ of 2/2.6 mm Hg in SBP/DBP with yoga (P &lt; .05/P &lt; .05), 5.3/6 mm Hg with brisk walk (P &lt; .05), and 2.6/3.7 mm Hg with reduction in salt intake (P &lt; .05/P &lt; .05); prominent reduction in BP with brisk walking (P &lt; .0001) compared with yoga</td>
<td>↓ in muscle strength and motion of extremities (P &lt; .001) and improvement in physical and mental well-being (P &lt; .05) in yoga group</td>
</tr>
<tr>
<td>Vogler et al., 2011&lt;sup&gt;99&lt;/sup&gt;</td>
<td>NECT, 8 wk</td>
<td>Sedentary elderly &gt; 55 y (n=38)</td>
<td>Yoga group: layyer modified yoga postures in 90 min sessions 1×/wk and 20 min of regular house practice (n=19); no-intervention control group (n=19)</td>
<td>Preintervention vs postintervention</td>
<td>No change in BP with yoga postintervention</td>
<td>↓ of 6.2 BPM in pulse rate (P &lt; .001); improvement in inflammation in joints and pain intensity</td>
</tr>
<tr>
<td>Singh et al., 2011&lt;sup&gt;100&lt;/sup&gt;</td>
<td>RCT, 40 d</td>
<td>Rheumatoid arthritis patients (n=88)</td>
<td>Yoga group: integrated yoga with cleansing practice, asanas, pranayama, meditation, and diet, 90 min/d, 6 d/wk (n=40); waitlist control group (n=40)</td>
<td>Preintervention vs postintervention and comparison between the groups</td>
<td>↓ of 7.3/1.5 mm Hg (P &lt; .001/P &lt; .01) in SBP/DBP with yoga intervention compared with preintervention; nonsignificant change in waitlist controls; reduction in BP with yoga (P &lt; .001) compared with waitlist controls</td>
<td>↓ of 9.58 BPM in pulse rate (P &lt; .001) in yoga group and 5.6 BPM (nonsignificant) in control group after postintervention follow-up period; improvements in state and trait anxiety (P &lt; .01) in both groups at follow-up; reduction in early morning stiffness in both groups</td>
</tr>
<tr>
<td>Ebenezer et al., 2011&lt;sup&gt;101&lt;/sup&gt;</td>
<td>RCT, 15 d with 3 mo follow up</td>
<td>Osteoarthritis patients (n=250)</td>
<td>Yoga group: stretching, asanas, relaxation, meditation, yoga philosophy, and physiotherapy in 60 min sessions (n=125); control group: therapeutic exercises, including loosening, stretching, and relaxation with music and physiotherapy in 60 min sessions (n=125)</td>
<td>Preintervention vs postintervention after follow-up period and comparison between groups</td>
<td>↓ of 21.3/14.3 mm Hg in SBP/DBP at postintervention after follow-up (P &lt; .001/P &lt; .01) in yoga group compared with preintervention; nonsignificant change in controls; reduction in BP with yoga (P &lt; .001) compared with controls after postintervention follow-up period</td>
<td>↓ of 9.58 BPM in pulse rate (P &lt; .001) in yoga group and 5.6 BPM (nonsignificant) in control group after postintervention follow-up period; improvements in state and trait anxiety (P &lt; .01) in both groups at follow-up; reduction in early morning stiffness in both groups</td>
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<tr>
<td>Gopalan, 2011[25]</td>
<td>RCT, 12 wk</td>
<td>Normotensive medical students with examination stress ($n = 66$)</td>
<td>Yoga group: integrated yoga practices with stretching, asanas, pranayama, and meditation in 35-min sessions/week ($n = 30$); control group ($n = 36$)</td>
<td>Preintervention vs postintervention</td>
<td>No change in BP in yoga group, whereas $T$ in SBP 3 mm Hg ($P &lt; .01$) in control group; mean rate pressure product lower in yoga group ($P &lt; .05$) compared with control during postintervention</td>
<td>No change in HR in yoga group, whereas $T$ of 4.67 BPM in HR ($P &lt; .001$) in control group postintervention; $T$ in HR ($P &lt; .01$) in control group; stress score lower in yoga group ($P &lt; .05$) than in controls</td>
</tr>
<tr>
<td>Chung et al., 2012[30]</td>
<td>NI RCT, 2 wk</td>
<td>Patients from meditation center or medical center, with heterogeneous health conditions ($n = 150$)</td>
<td>Yoga group: Adaptive yoga with breathing practice, exercises, and foot spa together with standard medication ($n = 67$); control group: conventional medication ($n = 62$)</td>
<td>Preintervention vs postintervention and comparison between the groups</td>
<td>$\downarrow$ of 12.3 mm Hg and 6.4 mm Hg in DBP ($P &lt; .001$) in hypertensive individuals with diabetes and hypertensive individuals without diabetes, respectively; with yoga postintervention compared with preintervention: reduction in DBP in yoga group ($P = .004$) compared with hypertensive patients in conventional treatment group</td>
<td>Improvement in all domains of quality of life ($P &lt; .001$) in yoga group compared with controls</td>
</tr>
<tr>
<td>Ives et al., 2012[35]</td>
<td>RCT, 8 wk</td>
<td>Postmenopausal overweight women with RLS ($n = 75$)</td>
<td>Yoga group: Hatha yoga with 23 restorative poses involving pranayama and relaxation in 90-min sessions 2×/wk and home practice ($n = 30$); control group: educational film and brief discussion with health professional in 90-min sessions 2×/wk ($n = 37$)</td>
<td>Preintervention vs postintervention and comparison between groups</td>
<td>$\downarrow$ of 20.25$9.38$ mm Hg in SBP/DBP ($P &lt; .004/P &lt; .02$) in yoga group postintervention, compared with preintervention; no significant change in controls; reductions in yoga group ($P &lt; .05/P &lt; .03$) compared with controls postintervention</td>
<td>Improvements in multiple domains of mood state and sleep quality, anxiety, and perceived stress in yoga group ($P &lt; .05$) compared with controls postintervention</td>
</tr>
<tr>
<td>Tracy et al., 2012[32]</td>
<td>RCT, 8 wk</td>
<td>Sedentary young adult non-athletes ($n = 31$)</td>
<td>Yoga group: Hatha yoga in series of 26 guided postures performed in heated and humid studio, 24 sessions each of 90 min ($n = 15$); no-intervention control group ($n = 11$)</td>
<td>Preintervention vs postintervention</td>
<td>No change in BP in either group</td>
<td>$\uparrow$ in flexibility and musculoskeletal fitness in yoga group compared with preintervention; no change in aerobic fitness in yoga group</td>
</tr>
<tr>
<td>Kim et al., 2012[31]</td>
<td>RCT, 8 mo</td>
<td>Sedentary premenopausal women ($n = 34$)</td>
<td>Yoga group: chatanaga yoga, 60 min each session 2×/wk ($n = 16$); control group: daily lifestyle monitored by questionnaire at 2-mo intervals ($n = 18$)</td>
<td>Preintervention vs postintervention</td>
<td>No change in BP in either group</td>
<td>Improvement in muscle strength ($P &lt; .01$) in yoga group that is controls; no significant change in body flexibility in either group</td>
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Abbreviations: BPM = beats per min; HRV = heart rate variability; PMR = progressive muscle relaxation; RLS = restless leg syndrome.
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<tr>
<td>Joseph et al., 1981</td>
<td>Cohort, 3 mo</td>
<td>Normotensive (n = 10)</td>
<td>Integrated yoga—prayer, asana, pranayama, and meditation</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 3.7 mm Hg in S/D/DP (P &lt; .01/P &lt; .01) with yoga postintervention compared with preintervention</td>
<td>↓ of 5 BPM in HR (P &lt; .001); ↓ in blood glucose (P &lt; .001); ↓ in cholesterol and lipoprotein (P &lt; .001)</td>
</tr>
<tr>
<td>Telles et al., 1993</td>
<td>Cohort, 3 mo</td>
<td>Normotensive (n = 30)</td>
<td>Residential comprehensive yoga program</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 9.47 mm Hg S/D/DP (P &lt; .05/P &lt; .001) with yoga postintervention compared with preintervention</td>
<td>↓ of 3 BPM in HR; ↓ of 6.9 kg in body weight (P &lt; .05) postintervention</td>
</tr>
<tr>
<td>Sachdeva, 1994</td>
<td>Cohort, 3 mo</td>
<td>Hypertensive and healthy (n = 46); hypertensive group (n = 26); normotensive group (n = 20)</td>
<td>Yogic lifestyle training—asses, pranayama, meditation, diet, and behavioral modification with lifestyle</td>
<td>Preintervention vs postintervention</td>
<td>Significant progressive reduction in BP in both populations</td>
<td>Significant progressive reduction in body weight, serum cholesterol, and triglyceride levels in both hypertensive and normotensive groups</td>
</tr>
<tr>
<td>Dhumodar et al., 2002</td>
<td>Cohort, 3 mo</td>
<td>Hypertensive (n = 7)</td>
<td>Comprehensive yogic intervention—postures, breathing, yoga nidra, yoga philosophy, and prayer</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 22/17.4 mm Hg in S/D/DP with yoga postintervention compared with preintervention (P values not provided)</td>
<td>↓ in blood glucose, lipid profile; improvement in subjective well-being; reduction in drug score</td>
</tr>
<tr>
<td>Singh et al., 2004</td>
<td>Cohort, 40 d</td>
<td>Type 2 diabetes (n = 24)</td>
<td>13 yoga postures in sequence</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 10/12 mm Hg in S/D/DP with yoga postintervention (P values not provided)</td>
<td>↓ of 0.8 BPM in pulse rate; ↓ of 48.6 and 74.8 mL/All in fasting and postprandial blood glucose levels, respectively (P values not provided)</td>
</tr>
<tr>
<td>Sivasankaran et al., 2000</td>
<td>Cohort, 6 wk</td>
<td>Adults with and without CAD risk factors (n = 33)</td>
<td>Integrated yoga practices involving asanas, pranayama, meditation, and relaxation for 90 min/session, 3 d/wk</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 5/5 mm Hg in S/D/DP (P = .01/P &lt; .01) with yoga postintervention compared with preintervention; hemodynamic parameters improved to lesser extent in individuals with CAD risk factors</td>
<td>↓ of 9 BPM in HR (P &lt; .01); improvement in BMI (P &lt; .01) with yoga postintervention; no change in lipid index and glycemic profile</td>
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<td>Karunagari, 2007</td>
<td>Cohort, 3 mo</td>
<td>Normotensive (n = 98)</td>
<td>Yoga intervention—sun salutation, pranayama, meditation, relaxation</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 6.2 mm Hg in S/D/DP (P &lt; .001) with yoga postintervention</td>
<td>↓ of 7.8 BPM in pulse rate (P &lt; .001); ↓ in body weight (P &lt; .001); serum cholesterol (P &lt; .001), and blood sugar (P &lt; .001)</td>
</tr>
<tr>
<td>Gokal et al., 2007</td>
<td>Cohort, 7 d</td>
<td>Heterogeneous population with CVD risk factors (n = 428)</td>
<td>Yoga intervention—asana, pranayama, meditation</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 8/5 mm Hg in S/D/DP (P &lt; .001/P &lt; .01) with yoga postintervention compared with preintervention</td>
<td>↓ in body weight (P &lt; .001), BMI (P &lt; .001), blood glucose (P &lt; .01), and cholesterol (P &lt; .001)</td>
</tr>
<tr>
<td>Chen et al., 2008</td>
<td>Cohort, 4 wk</td>
<td>Senior &gt; 60 y (n = 16)</td>
<td>Complete silver yoga program, 70 min/session</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 18.3 mm Hg in S/D/DP (P &lt; .05) with yoga postintervention compared with preintervention</td>
<td>↓ in body fat percentage (P &lt; .001)</td>
</tr>
<tr>
<td>Thornley et al., 2011</td>
<td>Cohort, 6 wk</td>
<td>Normotensive (n = 50)</td>
<td>Integrated yoga—asana with mindful breath, movement, meditation, and philosophical concepts</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 2.7 mm Hg in D/D/P (&lt; .05) with yoga postintervention compared with preintervention</td>
<td>↓ in body weight (P &lt; .001) and body fat (P &lt; .001)</td>
</tr>
<tr>
<td>Murphy et al., 2011</td>
<td>Cohort, 21 d with 12 mo of follow-up</td>
<td>Hypertensive medically treated (n = 104)</td>
<td>Integrated yoga with naturopathic treatment modality and dietary management</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 10/5.1 mm Hg in S/D/DP (P &lt; .001) with yoga postintervention compared with preintervention</td>
<td>Improvement in lipid index with yoga postintervention; reduction in drug score; 24.56% of participants maintained BP in normal range without medication during follow-up period</td>
</tr>
</tbody>
</table>

Tyagi—Yoga and Hypertension
in BP and the lipid index after 12 months. A further cohort reported improvement in BP, despite unchanged lipid and glycerol profile for volunteers with and without CAD risk factors.

**Controlled Studies on Integrated Yoga Practice for Cardiac Risk Factors**

The improvements in CVD risk factors seen in cohort studies are consistent with several RCTs and NRCTs involving various yoga practices in hypertensive or normotensive people (Table 8). An early study that examined the effects of yoga practices in three yoga practices reporting in reductions in BP, blood glucose, and body weight, while the practice of a rhythmic sequence of postures (suni salutations) alone resulted in increases in BP and body weight, despite reductions in blood glucose.

NRCTs of an integrated yoga approach also reported reductions in BP and improvements in metabolic variables for both healthy and diseased populations compared with nonintervention controls. Significant falls in BP, cholesterol, and triglycerides in hypertensive participants were reported after 7 weeks, while significant falls in BP, pulse rate, and body weight were reported in healthy participants after 2 months. Significant reductions in BP, glycerol index, and BMI were also reported after 3 months of yoga practice in type 2 diabetic individuals. Similarly, a 9-month study reported reductions in SBP, pulse rate, and blood glucose in geriatric participants with HPT and diabetes.

A reduction in blood cholesterol and body weight was seen in hypertensive participants compared with normotensive participants who were attending a 3-month residential yoga training program.

Not all controlled trials of yoga reported reductions in CVD risk factors other than BP. A 2-month study reported reductions in BP but not in other CVD risk factors in hypertensive patients practicing *sadhanam kriya* and similar results were reported in a 3-month study of normotensive people practicing integrated yoga. The improvements in multiple cardiac risk factors seen in cohort and NRCTs were consistent with the results from RCTs. A significant reduction in BP was reported in a 3-month study in hypertensive patients, and significant reductions in BP and BMI were seen in an 8-week study involving an experimental group practicing yoga techniques, stress reduction, and health management compared with inactive controls. Furthermore, an 11-week study reported significant reductions in BP for a yoga group that were similar to those achieved by a group on antihypertensive medications, with significant reductions in body weight being observed in the yoga group but not in the medication group.

Improvement in cardiovascular reactivity including BP, waist circumference, glycemic control, and lipid profile were reported in two 3-month studies of metabolic-syndrome patients randomly assigned to a yoga intervention compared with unchanged results in those assigned to usual care. Similar results were reported in a recent controlled trial of metabolic-syndrome patients randomly assigned either to 16 weeks of yoga or to no intervention. A further 6-month RCT involving CAD patients also found significant reductions in BP and significant improvements in lipid profiles in the yoga group.

In contrast, 3 RCTs ranging from 10 weeks to 20 weeks that compared yoga interventions to active, no-intervention, or usual-care controls found no improvement in BP, glycemic index, or lipid profiles with yoga interventions in HIV infected patients, metabolic syndrome patients, and type 2 diabetic patients.

**Studies on Yoga-type Interventions, Biofeedback, and HPT**

Biofeedback involves the use of an electronic device to monitor and provide feedback on specific physiological states (Table 9). This technique has been used in several studies of elevated BP where yogic relaxation has been used for behavior modification and stress reduction. In a series of 9 separate studies that spanned a period of over 15 years, Patel et al consistently demonstrated that a combination of yoga relaxation and biofeedback was effective in reducing BP, medication requirements, and cardiovascular risk in hypertensive patients. In these studies, the yoga intervention involved participants being asked to pay attention to their breathing and engage in a yogic relaxation practice that involved mentally relaxing the various parts of the body and then focusing the mind on an object of concentration while receiving feedback on the status of their sympathetic nervous system from a galvanic skin resistance (GSR) device with an audio output.
<table>
<thead>
<tr>
<th>Authors and Year</th>
<th>Design and Duration</th>
<th>Population</th>
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<th>Comparisons</th>
<th>BP Outcomes</th>
<th>Other Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Udupa et al, 1975[13]</td>
<td>NRCT, 6 mo</td>
<td>Normotensive (n = 10)</td>
<td>Yoga postures—set 1 group: headstand, cobra, locust, and peacock poses (n = 4); set 2 group: shoulder stand, fish, plow, and forward bend (n = 6); sun salutation group (n = 4)</td>
<td>Preintervention vs postintervention</td>
<td>+ of 9/7 mm Hg in SBP/DBP in set 1; + of 8 mm Hg in DBP in set 2; + of 3/20 mm Hg in BP in sun salutation group (P values not provided)</td>
<td>+ in pulse rate; + in body weight 1.3 kg in set 1; 3.2 kg in body weight with sun salutation; + in fasting blood sugar in all (P values not provided)</td>
</tr>
<tr>
<td>Telukdar et al, 1996[12]</td>
<td>NRCT, 1 mo</td>
<td>Hypertensive (n = 30); healthy, age- and BMI-matched controls (n = 30)</td>
<td>Yoga techniques—vịścera cleansing, stretching, postural, and breathing for both groups</td>
<td>Preintervention vs postintervention</td>
<td>+ of 14/2.12 mm Hg in SBP/DBP (P &lt; .01) in hypertensive group with postintervention compared with preintervention; nonsignificant drop of 4/4.1 mm Hg in healthy group</td>
<td>+ of 5.3 mg/dL (P &lt; .05) in HDL; − of 23 mg/dL in plasma triglycerides (P &lt; .01) and of 14 mg/dL in plasma cholesterol (P &lt; .01) in hypertensive group; similar significant trend in healthy group</td>
</tr>
<tr>
<td>Schmidt et al, 1979[14]</td>
<td>NRCT, 3 mo</td>
<td>Normotensive (n = 106)</td>
<td>Residential krivá yoga group: complete yoga lifestyle training, including diet, and control group</td>
<td>Preintervention vs postintervention</td>
<td>+ of 21/13 mm Hg and 15/7 mm Hg in SBP/DBP (P &lt; .0001 and P &lt; .01) in males and females, respectively</td>
<td>− in HR (P &lt; .005); + of 5.7 kg in body weight (P &lt; .02); − in serum cholesterol and LDL cholesterol (P &lt; .001) in men</td>
</tr>
<tr>
<td>Maruigean et al, 2000[15]</td>
<td>RCT, 11 wk</td>
<td>Hypertensive (n = 33)</td>
<td>Integrated yoga group: aasana, pranayama, meditation, chanting, and relaxation (n = 11); anti-hypertensive drug group (n = 11); no-intervention control group (n = 11)</td>
<td>Preintervention vs postintervention</td>
<td>+ of 33.6 to 26.2 mm Hg in SBP/DBP (P &lt; .01) with yoga postintervention; + of 23.76 to 9.9 mm Hg in SBP/DBP (P &lt; .01) with drugs compared with preintervention; no change in controls</td>
<td>− of 27.8 BPM in pulse rate (P &lt; .01) with yoga postintervention and 16.8 in BPM (P &lt; .01) with drugs postintervention; − of 7.4 kg in body weight (P &lt; .05) with yoga postintervention</td>
</tr>
<tr>
<td>McCaffrey et al, 2005[16]</td>
<td>RCT, 8 wk</td>
<td>Hypertensive (n = 61)</td>
<td>Yoga group: breathing and postures, stress reduction techniques, and health information; control group: awareness on hypertension</td>
<td>Preintervention vs postintervention</td>
<td>+ of 24.9/17.51 mm Hg in SBP/DBP (P &lt; .01) with yoga postintervention compared with preintervention; no change in controls</td>
<td>+ of 1.85 BPM in HR (P &lt; .01); − of 0.34 in BMI (P &lt; .05); − in stress scores (P &lt; .01) in yoga group compared with preintervention</td>
</tr>
<tr>
<td>Khani et al, 2007[17]</td>
<td>RCT, 3 mo</td>
<td>Metabolic syndrome (n = 101)</td>
<td>Yoga and meditation intervention group (n = 55); usual-care control group (n = 46)</td>
<td>Preintervention vs postintervention</td>
<td>+ of 15.2/7.7 mm Hg in SBP/DBP (P &lt; .01) with yoga postintervention compared with preintervention; no change in usual-care controls</td>
<td>− in waist circumference, fasting blood glucose, and serum triglycerides (P &lt; .01) and improvement in HDL cholesterol (P &lt; .001) with yoga postintervention</td>
</tr>
<tr>
<td>Cohen et al, 2008[18]</td>
<td>RCT, 10 wk</td>
<td>Metabolic syndrome (n = 26)</td>
<td>Restorative yoga group: poses using props and relaxation techniques (n = 13); usual-care group (n = 23)</td>
<td>Preintervention vs postintervention and comparison between groups</td>
<td>Non-significant change in BP in both groups</td>
<td>Non-significant changes in BMI and weight and lipid profile</td>
</tr>
<tr>
<td>Covidianu, 2009[19]</td>
<td>NRCT, 12 wk</td>
<td>Geriatric hypertensive population (n = 27)</td>
<td>Yoga postures, breathing, and mantra chanting (n = 27); physical exercise group: callisthenics, walking, breathing, and relaxation (n = 9); no-intervention control group (n = 9)</td>
<td>Preintervention vs postintervention</td>
<td>Similar significant reduction in SBP in yoga and exercise groups; no change in controls</td>
<td>Significant reduction in pulse rate and blood sugar in yoga and exercise group</td>
</tr>
<tr>
<td>Skoro-Konizha et al, 2009[20]</td>
<td>RCT, 3 mo</td>
<td>Type 2 diabetes (n = 59)</td>
<td>Integrated yoga group: yoga techniques in 90-min sessions 2 x/wk (n = 29); usual-care control group (n = 30)</td>
<td>Preintervention vs postintervention</td>
<td>No change in BP in either group</td>
<td>Non-significant change in HbA1c, no change in lipid levels in either group, poor adherence to class attendance</td>
</tr>
</tbody>
</table>
## Table 8. (continued)

<table>
<thead>
<tr>
<th>Authors and Year</th>
<th>Design and Duration</th>
<th>Population</th>
<th>Intervention</th>
<th>Comparisons</th>
<th>BP Outcomes</th>
<th>Other Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jain et al, 2010*</td>
<td>NBCT, 2 mo</td>
<td>Normotensive (n = 87)</td>
<td>Integrated yoga group: practice of stretching, sun salutation, asanas, pranayama, meditation (n = 57); no intervention control group (n = 30)</td>
<td>Preintervention vs postintervention</td>
<td>4 of 4.99/3.47 mm Hg in SBP/DBP (P &lt; .05/P &lt; .01) in yoga group compared with preintervention; no change in controls</td>
<td>4 of 1.72 BPM in pulse (P &lt; .001); 4 of 3.51 kg in body weight (P &lt; .05) in yoga group compared with preintervention</td>
</tr>
<tr>
<td>Cade et al, 2010*</td>
<td>RCT, 20 wk</td>
<td>HIV patients with CVR risk factors (n = 60)</td>
<td>Yoga intervention group: asana, pranayama, focused gaze, bandhas, and relaxation (n = 34); usual care control group (n = 26)</td>
<td>Preintervention vs postintervention and comparison between groups</td>
<td>No change in BP in either group</td>
<td>Nonsignificant reduction in body weight after yoga; reduction in LDL/cholesterol parameters in yoga group compared with usual care group</td>
</tr>
<tr>
<td>Cohen et al, 2011*</td>
<td>RCT, 12 wk</td>
<td>Hypertensive (n = 78)</td>
<td>Yoga group: iyengar yoga involving asanas, and pranayama (n = 66); ECU group: motivational and behavioral education with diet and disease awareness (n = 32)</td>
<td>Preintervention vs postintervention</td>
<td>4 of 6.5/1.3 mm Hg in SBP/DBP (P &lt; .05/P &lt; .01) with yoga postintervention; nonsignificant drop of 4 of 4.2 mm Hg in SBP/DBP in ECU group</td>
<td>No change in HR for both groups; no change in BMI with yoga</td>
</tr>
<tr>
<td>Yang et al, 2011*</td>
<td>RCT, 3 mo</td>
<td>Metabolic syndrome (n = 23)</td>
<td>Vyasa yoga group: series of postures with breathing and relaxation in 60-min session 2 x/week, with home practice (n = 12); general health awareness group (n = 11)</td>
<td>Preintervention vs postintervention and comparison between groups</td>
<td>4 of 5.2/0.58 mm Hg in SBP/DBP in yoga group compared with controls; nonsignificant difference between groups</td>
<td>Prominent reduction in body weight and lipid and glycemic parameters in yoga group compared with control</td>
</tr>
<tr>
<td>Hegde et al, 2011*</td>
<td>NBCT, 3 mo</td>
<td>Type 2 diabetic patients (n = 123)</td>
<td>Integrated yoga group; practice 3 x/week (n = 60); control group (n = 63)</td>
<td>Preintervention vs postintervention</td>
<td>Nonsignificant change in BP in yoga group compared with preintervention</td>
<td>Significant improvements in BMI and glycemic parameters in yoga group; improvement in markers of oxidative stress in yoga group</td>
</tr>
<tr>
<td>Agte et al, 2011*</td>
<td>NBCT, 2 mo</td>
<td>Normotensive and hypertensive (n = 52); hypertensive group (n = 26); normotensive control group (n = 20)</td>
<td>Sudarshan kriya yoga to both groups in 30-min session 6 x/week and in 75-min session 1 x/week</td>
<td>Preintervention vs postintervention</td>
<td>4 of 4.2 mm Hg in DBP (P &lt; .01) in hypertensive group compared with preintervention; no change in normotensive group</td>
<td>No significant change in lipid and glycemic parameters in hypertensive group; improvement in markers of oxidative stress (P &lt; .05) in hypertensive group</td>
</tr>
<tr>
<td>Pal et al, 2011*</td>
<td>RCT, 6 mo</td>
<td>CAD patients with other comorbidities (n = 170)</td>
<td>Yoga group: postures with nasal cleansing in 40-min sessions regularly (n = 85); no-intervention control group (n = 85)</td>
<td>Preintervention vs postintervention</td>
<td>4 of 11.02/8.9 mm Hg in SBP/DBP (P &lt; .05) in yoga group compared with preintervention; no change in controls</td>
<td>4 of 4.2 BPM in HR (P &lt; .0001); 4 in EMI (P &lt; .04) and total cholesterol and triglycerides (P &lt; .0001) in yoga group</td>
</tr>
<tr>
<td>Deepa et al, 2012*</td>
<td>NBCT, 3 mo</td>
<td>Hypertensive (n = 30)</td>
<td>Yoga intervention group: asana, pranayama, meditation, and yoga nidra together with anti-hypertensive therapy (n = 15); control group: any hypertensive therapy (n = 15)</td>
<td>Preintervention vs postintervention</td>
<td>4 of 18.3/14.7 mm Hg in supine SBP/DBP in yoga group and 4 of 16.3/4.4 mm Hg in supine SBP/DBP in medication therapy group compared with preintervention (P values not precised)</td>
<td>4 of 8.5 BPM in pulse rate in yoga group; compared with preintervention; no improvement in lipid profile in either group (P values not provided)</td>
</tr>
<tr>
<td>Lee et al, 2012*</td>
<td>RCT, 16 wk</td>
<td>Postmenopausal women (n = 16)</td>
<td>Yoga group: yoga postures coordinated with breathing techniques and periods of relaxation (n = 8); no intervention control group (n = 8)</td>
<td>Preintervention vs postintervention and comparison between groups</td>
<td>4 of 8.6/8.25 in SBP/DBP (P &lt; .001/P &lt; .01) in yoga group compared with preintervention; reduction in BP in yoga group (P &lt; .001), compared with controls</td>
<td>4 in cholesterol (P &lt; .01), triglycerides (P &lt; .05), and glucose (P &lt; .05) in yoga group compared with preintervention</td>
</tr>
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</table>

Abbreviations: BPM = beats per minute; HbA1c = glycated hemoglobin.
The first study, which involved hypertensive patients who attended a 30-minute session of biofeedback and yogic relaxation over 3 months, reported a reduction in BP with a 41% reduction in antihypertensive medication, in a study of the same duration with a similar intervention, hypertensive patients experienced significant reductions in BP (BP) together with a 42% reduction in medication at the end of the follow-up period. In a subsequent study of the same duration, a significant number of hypertensive patients on antihypertensive medication, Patel et al found that yoga and biofeedback, together with home practice, significantly reduced BP with a 41% reduction in antihypertensive medication at the end of the follow-up period. In a subsequent crossover study, a similar intervention over 6 weeks was shown to result in significant drops of BP in hypertensive patients.

In addition to improving HPT, the yoga and biofeedback intervention used by Patel et al was demonstrated to improve other coronary risk factors. In a 6-week study, pharmacologically treated hypertensive patients were found to experience significant reductions in BP and serum cholesterol, and a further study with hypertensive patients using the same intervention also resulted in a significant reduction in BP, together with a significant reduction in cholesterol and triglyceride levels. The same authors performed another unblinded RCT in 249 participants with two or more coronary risk factors, in which both groups received general health education, while the treatment group (n = 99) also received weekly 1-hour group biofeedback and yoga sessions for 8 weeks, together with twice daily home practice and a stress education program. After 8 months, BP fell significantly in all participants in the treatment group, with a more prominent fall in BP in hypertensive participants. A further 4-year follow-up of these participants revealed that reductions in cholesterol and smoking were no longer maintained while the reductions in BP were maintained in both hypertensive and normotensive participants within the treatment group but not in the control group, which also experienced significantly more cardiovascular events. Using a subset of participants from a larger drug trial, the same researchers found significant reductions in BP and cardiovascular events at 8 weeks in a relaxation group compared with a control group that did not receive the relaxation therapy, with the results being maintained after 1 year of follow-up.

In addition to the studies by Patel et al, a number of small studies reported reductions in BP with biofeedback and yogic interventions that involved slow, focused, relaxed breathing. These studies included an early case report of a hypertensive patient with periodic angina pectoris treated with various medications, who underwent breath meditation assisted by EMG biofeedback twice per day and experienced significantly lower BP after 8 months of follow-up. Another case study incorporating biofeedback, yogic relaxation, and yogic lifestyle changes reported a reduction in BP after 6 weeks, with the reductions maintained after 6 months despite withdrawal of antihypertensive medication. Reducions in BP with biofeedback and yoga were also reported in hypertensive patients who underwent 2 months of shavasana training and 4 weeks of yoga relaxation focusing on slow breathing, assisted by instrumental music. These results were consistent with the results of RCTs that found significant falls in BP with 1 month of biofeedback and slow breathing, 2 months of biofeedback and meditation, 2 months of biofeedback and shavasana, and 6 months of thermal biofeedback together with an integrated yoga intervention.

Studies on RESPERATE-facilitated Breathing and HPT

The RESPERATE device uses specifically timed music to entrain slow yoga-style breathing at 10 BPM with prolonged exhalation (Table 10). The RESPERATE device has been used in a number of clinical trials of hypertensive patients, including RCTs, an NRCT, cohort studies, and a case report. Reductions in BP have been reported with daily use of RESPERATE in 2 small cohort studies involving only hypertensive patients. Of these, 1 study reported that use of RESPERATE resulted in a significant fall in systolic BP for 13 hypertensive patients, measured via 24-hour ambulatory BP monitoring, and the other reported a significant fall in BP for 17 hypertensive patients, measured in clinical as well as home settings. Significant reductions in BP were also reported in an 8-week trial involving 48 hypertensive patients using the RESPERATE compared with 31 control participants who underwent no intervention, as well as in a case report of an elderly hypertensive patient with COPD. These results have been further supported by a series of RCTs.

A double-blind, randomized, placebo-controlled trial involving 33 hypertensive patients randomly assigned either to the RESPERATE (n = 18) or passive music (n = 17) for 8 weeks resulted in significant falls in BP in the treatment group. A similar 8-week, double-blind study of 65 hypertensive patients, randomly assigned either to the RESPERATE or passive music, reported similar significant reductions in BP that continued after 6 months of follow-up. A further double-blind RCT of 149 hypertensive patients found impressive reductions in BP after 8 weeks, with significant reductions seen only in regular users (>180 min/week). Similarly, an 8-week RCT of 66 NIDDM and hypertensive participants, who randomly received either (1) the RESPERATE for 15 minutes 3 times per week or (2) usual care, found that the treatment group experienced significant drops in BP with greater reductions being associated with greater compliance and adherence. More recently, another RCT involving 40 borderline hypertensive patients assigned either to the RESPERATE or spontaneous breathing while repeating the word "one at each exhalation reported significantly greater reductions in BP in the device-guided breathing group compared with pretreatment and to the passive control-breathing groups.

In contrast to the above results, a number of relatively small studies have not shown significant reductions in BP in RESPERATE users compared with those listening passively.
Chapter 5
Yoga and Hypertension: A Systematic Review

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<tr>
<th>Authors and Year</th>
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<tbody>
<tr>
<td>Patel, 1973&lt;sup&gt;13&lt;/sup&gt;</td>
<td>Cohort, 3 mo</td>
<td>Hypertensive (n = 20)</td>
<td>Biofeedback-aided yoga relaxation</td>
<td>Preintervention vs postintervention</td>
<td>4 of 26/16 mm Hg in SBP/DBP compared with preintervention (P values not provided)</td>
<td>41% reduction in medication</td>
</tr>
<tr>
<td>Patel, 1973&lt;sup&gt;14&lt;/sup&gt;</td>
<td>NRCT, 3 mo with 12 mo of follow-up</td>
<td>Hypertensive (n = 46)</td>
<td>Biofeedback-aided yoga relaxation group (n = 20); control group (n = 20)</td>
<td>Preintervention vs postintervention</td>
<td>4 of 26.4/14.2 mm Hg in SBP/DBP (P &lt; .001/P &lt; .001) after 3 mo of intervention and stable BP at reduced levels at the follow-up</td>
<td>42% reduction in medication in treatment group</td>
</tr>
<tr>
<td>Patel et al., 1975&lt;sup&gt;16&lt;/sup&gt;</td>
<td>Crossover RCT, phase 1, 6 wk with 3 mo of follow-up phase 2, 2 mo of washout and 6 wk of treatment</td>
<td>Hypertensive (n = 34)</td>
<td>Biofeedback-aided yoga relaxation group (n = 17); control group (n = 17)</td>
<td>Preintervention vs postintervention and comparison between interventions</td>
<td>4 of 26.4/15.2 mm Hg in SBP/DBP (P values not provided) in treatment group in phase 1; difference of 17.2/11.1 mm Hg in SBP/DBP (P &lt; .005/P &lt; .001) between groups in phase 2</td>
<td>4 of 28.1/15.4 mm Hg in SBP/DBP (P values not provided) after 2 mo of washout in control group in phase 2</td>
</tr>
<tr>
<td>Patel et al., 1976&lt;sup&gt;16&lt;/sup&gt;</td>
<td>NRCT, 9 wk with 6 mo of follow-up</td>
<td>Hypertensive (n = 47)</td>
<td>Biofeedback-aided relaxation group (n = 37); control group (n = 10)</td>
<td>Preintervention vs postintervention</td>
<td>4 of 17.5/13.3 mm Hg in SBP/DBP (P &lt; .001/P &lt; .001) with treatment; 77% of participants in treatment group benefited at the end of follow-up, despite reductions in medication; no change in controls</td>
<td>41% reductions in medication at follow-up in treatment group</td>
</tr>
<tr>
<td>Patel, 1976&lt;sup&gt;16&lt;/sup&gt;</td>
<td>Cohort, 6 wk</td>
<td>Medically treated hypertensive (n = 14)</td>
<td>Biofeedback-aided relaxation</td>
<td>Preintervention vs postintervention</td>
<td>4 of 22.7/13.4 mm Hg in SBP/DBP (P &lt; .001/P &lt; .001) compared with preintervention</td>
<td>4 of 24.3 mg/109 mL in serum cholesterol (P &lt; .001); body weight remained stable</td>
</tr>
<tr>
<td>Patel et al., 1977&lt;sup&gt;16&lt;/sup&gt;</td>
<td>NRCT, 6 wk</td>
<td>Hypertensive individuals and non-smokers, &gt; 10 cigarettes/d (n = 76)</td>
<td>Biofeedback-aided relaxation: hypertensive group (n = 18); smoking group (n = 18); control group (n = 18)</td>
<td>Preintervention vs postintervention</td>
<td>4 of 18.6/11.2 mm Hg (P &lt; .005/P &lt; .005) of 8.2/1.9 (P &lt; .05) /non-significant and of 9.7/7 mm Hg (P &gt; .05/P &lt; .05) in SBP/DBP for hypertensive, smokers, and non-smoker groups, respectively, with yoga postintervention compared with preintervention; no change in control group</td>
<td>4 in HR (P &lt; .05) and (P &lt; .05) in hypertensive group and smoking group, respectively, nonsignificant reduction in body weight in both groups; 4 in cholesterol and triglyceride levels in hypertensive group; significant reduction in smoking in smoking group</td>
</tr>
<tr>
<td>Rappaport et al., 1977&lt;sup&gt;34&lt;/sup&gt;</td>
<td>Case report, 1 mo with 8 mo of follow-up</td>
<td>Hypertensive (n = 1)</td>
<td>Biofeedback relaxation with breath-focused meditation</td>
<td>Preintervention vs postintervention</td>
<td>4 of 35/15 mm Hg SBP/DBP at follow-up</td>
<td>4 in HR (P &lt; .05) and (P &lt; .05) in hypertensive group and non-smokers group, respectively, significant reduction in body weight in both groups; 4 in cholesterol and triglyceride levels in hypertensive group; significant reduction in smoking in smoking group</td>
</tr>
<tr>
<td>Diter, 1980&lt;sup&gt;16&lt;/sup&gt;</td>
<td>NRCT, 8 wk</td>
<td>Hypertensive (n = 20)</td>
<td>Biofeedback and yogic relaxation group (n = 10); control group: resting on couch (n = 10)</td>
<td>Preintervention vs postintervention</td>
<td>Significant reduction in BP in treatment group; no change in controls</td>
<td>33% reduction in drug requirement for treatment group</td>
</tr>
<tr>
<td>Hafnor, 1982&lt;sup&gt;16&lt;/sup&gt;</td>
<td>RCT, 8 wk with 3 mo of follow-up</td>
<td>Hypertensive (n = 21)</td>
<td>Relaxation group: physical relaxation with instructions in visualization (n = 7); biofeedback group: facilitative relaxation by decreasing physiological arousal in weekly session (n = 8); no-intervention control group (n = 7)</td>
<td>Preintervention vs postintervention</td>
<td>4 of 14.5/12.6 mm Hg (P &lt; .05/P &lt; .01) and 20.8/14.7 mm Hg (P &lt; .05/P &lt; .01) in SBP/DBP in relaxation and biofeedback groups, respectively, at the end of follow-up; no change in controls</td>
<td>4 in HR (P &lt; .05) and (P &lt; .05) in hypertensive group and smoking group, respectively, significant reduction in body weight in both groups; 4 in cholesterol and triglyceride levels in hypertensive group; significant reduction in smoking in smoking group</td>
</tr>
</tbody>
</table>
### Table 9. (continued)

<table>
<thead>
<tr>
<th>Authors and Year</th>
<th>Design and Duration</th>
<th>Population</th>
<th>Intervention</th>
<th>Comparisons</th>
<th>BP Outcomes</th>
<th>Other Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patel et al., 1981&lt;sup&gt;18&lt;/sup&gt;; Patel et al., 1985&lt;sup&gt;26&lt;/sup&gt;</td>
<td>ECT, unblinded for 8 mo with 4 yr of follow-up</td>
<td>Two or more coronary risk factors: hyperensive, elevated serum cholesterol, or smoking &gt; 10 cigarettes/d (n = 264)</td>
<td>Biofeedback-aided relaxation group (n = 99); health education control group (n = 95)</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 15.3/6.4 mm Hg in SBP/DBP (P &lt; .001/P &lt; .001) after 8 mo of follow-up in treatment group; ↓ of 22.4/11.5 mm Hg in SBP/DBP (P &lt; .001/P &lt; .001) in subgroup of hypertensive group at the end of follow-up</td>
<td>After 4 yr of follow-up, reduction in BP was maintained in hypertensive treatment group</td>
</tr>
<tr>
<td>Morga, 1966&lt;sup&gt;30&lt;/sup&gt;</td>
<td>Cohort, 2 mo</td>
<td>Hypertensive (n = 8)</td>
<td>Biofeedback-aided yogaic relaxation, 20 sessions</td>
<td>Preintervention vs postintervention</td>
<td>↓ of in 24 hs/14.3 mm Hg in SBP/DBP, compared with preintervention (P values not provided)</td>
<td></td>
</tr>
<tr>
<td>Patel et al., 1988&lt;sup&gt;37&lt;/sup&gt;</td>
<td>RCT, 8 wk with home practice and 12 mo of follow-up</td>
<td>Hypertensive (n = 163)</td>
<td>Biofeedback-aided relaxation group (n = 49); no-intervention control group (n = 54)</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 4.9/1.5 mm Hg in SBP/DBP (P &lt; .001/P &lt; .01) at the end of 1 yr of follow-up; no change in controls</td>
<td>Reduction in cardiovascular events in treatment group</td>
</tr>
<tr>
<td>Brownstein et al., 1990&lt;sup&gt;35&lt;/sup&gt;</td>
<td>Case report, 6 wk</td>
<td>Hypertensive (n = 1)</td>
<td>Biofeedback-aided relaxation with incorporation in daily activities of yogic lifestyle techniques.</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 16.6 mm Hg in SBP/DBP after 6 wk, compared with preintervention; BP remained stable at follow-up</td>
<td></td>
</tr>
<tr>
<td>Latha et al., 1991&lt;sup&gt;38&lt;/sup&gt;</td>
<td>NRCT, 6 mo, 17 sessions</td>
<td>Hypertensive (n = 14)</td>
<td>Yoga group: asanas, pranayama, and biofeedback-aided relaxation training (n = 7); no-intervention control group (n = 7)</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 6.9/5.6 mm Hg in SBP/DBP (P &lt; .05/P &lt; .01) compared with preintervention</td>
<td></td>
</tr>
<tr>
<td>Desai, 2001&lt;sup&gt;46&lt;/sup&gt;</td>
<td>Cohort, 4 wk</td>
<td>Hypertensive (n = 20)</td>
<td>Biofeedback-aided yogaic relaxation, asana practice with instrumental music</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 4.3/0.9 mm Hg in SBP/DBP (P &lt; .0001/P &lt; .0001) compared with preintervention</td>
<td></td>
</tr>
<tr>
<td>Wang et al., 2010&lt;sup&gt;48&lt;/sup&gt;</td>
<td>ECT, 1 yr with follow-up of 1 yr and 3 mo</td>
<td>Prehypertensive stage postmenopausal women (n = 26)</td>
<td>Biofeedback-aided relaxation and slow breathing (n = 13); control group (n = 13)</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 8.4/2.9 mm Hg in SBP/DBP (P &lt; .001/P &lt; .01) and stable values at follow-up in experimental group; ↓ of 4.3 mm Hg in SBP (P &lt; .01) but no remarkable effect at follow-up in controls</td>
<td>† RR interval (P &lt; .001) during biofeedback; no remarkable change in HRV</td>
</tr>
</tbody>
</table>

Abbreviations: RR = R within QRS complex of electrocardiogram; HRV = heart rate variability.
Table 10. Summary of Studies on RESPeRATE-facilitated Breathing and Hypertension

<table>
<thead>
<tr>
<th>Authors and Year</th>
<th>Design and Duration</th>
<th>Population</th>
<th>Intervention</th>
<th>Comparisons</th>
<th>BP Outcomes</th>
<th>Other Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schreiner et al., 2001</td>
<td>Double-blind placebo-controlled RCT, 8 wk and 6 mo of follow-up</td>
<td>Hypertensive (n = 61)</td>
<td>Group using modified breathing with iRESPeRATE (n = 32); control group: listening to music with self-monitoring of BP (n = 29)</td>
<td>Preintervention vs postintervention and comparison between groups</td>
<td>↓ of 15.2/10.5 mm Hg in SBP/DBP (P &lt; .0001), in device group and nonsignificant reduction in control group, compared with postintervention; postintervention difference between groups in SBP (P &lt; .008)</td>
<td>Stable results of BP in device group at follow-up</td>
</tr>
<tr>
<td>Grossman et al., 2001</td>
<td>Double-blind placebo-controlled RCT, 8 wk</td>
<td>Hypertensive (n = 30)</td>
<td>Group using modified breathing with RESPeRATE (n = 15); control group: listening to music (n = 15)</td>
<td>Preintervention vs postintervention and comparison between groups</td>
<td>↓ of 7.5/4 mm Hg and 2.9/1.5 mm Hg in SBP/DBP (P values not provided) in active group and control group, respectively, compared with preintervention; postintervention difference between groups in SBP/DBP (P &lt; .07/P &lt; .02)</td>
<td>↓ of 8 BPM in HR (P &lt; .05) in active group</td>
</tr>
<tr>
<td>Rosenthal et al., 2001</td>
<td>Cohort, 8 wk</td>
<td>Hypertensive (n = 13)</td>
<td>Group using modified breathing with RESPeRATE for 15 min and self-monitoring of BP</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 7.2 mm Hg in SBP (P &lt; .01) in 24-h ambulatory BP while awake</td>
<td></td>
</tr>
<tr>
<td>Visloper et al., 2003</td>
<td>Cohort, 8 wk</td>
<td>Hypertensive (n = 17)</td>
<td>Group using modified breathing with RESPeRATE for 15 min and self-monitoring BP</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 12.9/6.9 mm Hg in SBP/DBP (P &lt; .001/P &lt; .001) in clinical settings and ↓ of 6.4/3.6 mm Hg in SBP/DBP (P &lt; .05/P &lt; .05) in home settings in device group compared with preintervention</td>
<td></td>
</tr>
<tr>
<td>Elliott et al., 2004</td>
<td>Double-blind RCT, 8 wk</td>
<td>Hypertensive (n = 136)</td>
<td>Group using modified breathing with RESPeRATE for 15 min and self-monitoring of BP (n = 79); control group: self-monitoring of BP (n = 57)</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 10.6/5.2 mm Hg in SBP/DBP (P values not provided) in clinical settings in device group compared with preintervention; ↓ of 8/4.4 mm Hg in SBP/DBP (P &lt; .005/P &lt; .025) in high users compared with low users of device; no statistical difference in controls</td>
<td></td>
</tr>
<tr>
<td>Melis, 2004</td>
<td>NRCT, 8 wk</td>
<td>Hypertensive (n = 79)</td>
<td>Group using modified breathing with RESPeRATE for 15 min (n = 48), control group: self-monitoring of blood pressure (n = 31)</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 5.4/5.2 mm Hg in SBP/DBP (P &lt; .001/P &lt; .001) in home BP compared with preintervention; no significant change in controls</td>
<td></td>
</tr>
<tr>
<td>Elliott et al., 2006</td>
<td>Case report, 8 wk</td>
<td>Hypertensive with COPD and migraine (n = 1)</td>
<td>Group using modified breathing with RESPeRATE 2 x/4 for 15 min and BP monitoring</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 17/14 mm Hg in SBP/DBP (P &lt; .05/P &lt; .001)</td>
<td></td>
</tr>
<tr>
<td>Logeberg et al., 2007</td>
<td>Single-blind RCT, 8 wk</td>
<td>Diabetic hypertensive (n = 30)</td>
<td>Group using modified breathing with RESPeRATE and self-monitoring BP (n = 15); control group: random music and BP monitoring (n = 15)</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 7.4 mm Hg in SBP (P &lt; .0001) in device group; ↓ of 7.2 mm Hg in SBP (P &lt; .001) in control music group compared with preintervention</td>
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### Table 10. (continued)

<table>
<thead>
<tr>
<th>Authors and Year</th>
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<tbody>
<tr>
<td>Punzel et al., 2009&lt;sup&gt;69&lt;/sup&gt;</td>
<td>RCT, 16 wk</td>
<td>Hypertensive (n = 53)</td>
<td>Group using modified breathing with RESPeRATE 3 s/d for 1.5 min 3 s/wk and BP monitoring (n = 31); control group: random music and BP monitoring (n = 22)</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 0/8/15 mm Hg in SBP/DBP (P &lt; .12/P &lt; .001) in device group and ↓ of 16/8/4 mm Hg in SBP/DBP (P &lt; .001/P &lt; .001) in music group compared with preintervention</td>
<td></td>
</tr>
<tr>
<td>Schein et al., 2009&lt;sup&gt;70&lt;/sup&gt;</td>
<td>RCT, 8 wk</td>
<td>Hypertensive with type 2 diabetes (n = 46)</td>
<td>Group using modified breathing with RESPeRATE (n = 33); control group: continued with medication unchanged (n = 33)</td>
<td>Preintervention vs postintervention</td>
<td>↓ of 19/1.6 mm Hg in SBP/DBP (P &lt; .001/P &lt; .01) in device group compared with preintervention</td>
<td></td>
</tr>
<tr>
<td>Alcosa et al., 2009&lt;sup&gt;71&lt;/sup&gt;</td>
<td>Single-blind RCT, 9 wk</td>
<td>Hypertensive (n = 69)</td>
<td>Group using modified breathing with RESPeRATE (n = 15); control group: listening to music and monitoring BP (n = 15)</td>
<td>Comparison between groups</td>
<td>Nonsignificant postintervention difference in BP between the groups</td>
<td></td>
</tr>
<tr>
<td>Anderson et al., 2010&lt;sup&gt;72&lt;/sup&gt;</td>
<td>RCT, 4 wk</td>
<td>Hypertensive (n = 40)</td>
<td>Group using modified breathing with RESPeRATE (n = 20); control group: conscious breathing (n = 20)</td>
<td>Preintervention vs postintervention</td>
<td>↓ in SBP (&lt;.029) in treatment group compared with controls in clinic resting</td>
<td></td>
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</table>

Abbreviations: COPD = chronic obstructive pulmonary disease; BPM = beats per minute.

To relaxing music. In 1 single-blinded RCT involving 30 diabetic hypertensive patients, 8 weeks of either the RESPeRATE or random music resulted in similar significant reductions in BP in both groups, with no differences between the groups.<sup>68</sup> A similar result was reported in a 16-week RCT of 54 hypertensive patients that found a significant reduction in BP in both the participants who used the RESPeRATE and the participants who listened to slow relaxing music (n = 22).<sup>69</sup> Likewise, significant reductions in BP were noted in hypertensive patients who either used the RESPeRATE or listened to relaxing music, with no significant difference between the groups in a single-blinded RCT.<sup>70</sup>

**DISCUSSION**

Research performed over the past 40 years with various yoga interventions, including studies with different experimental designs, consistently reported reductions in BP together with reductions in other CVD risk factors such as lipid profile, glycemic index, weight, and Hr. The BP reductions reported with yoga were found in diverse populations, including adolescents and the elderly as well as both hypertensive and normotensive populations and unfit and athletic individuals. Yoga was also found to reduce BP in patients taking antihypertensive medications and to reduce medication use while maintaining reduced BP.

Of the 120 studies reviewed, 23 studies (including 12 RCTS) reported no change in BP with yoga practice. Thirteen of these studies<sup>69,71,72,73,73,74,74,75,75,76</sup> involved only a small number of normotensive participants (19 or fewer in each), and 1 cohort study of 64 participants reported no change in BP in young healthy adults despite an increase in cardiac output, stroke volume, and HR after yoga practice.<sup>102</sup> A further RCT reported no change in BP in 60 diabetic patients after 3 months of yoga practice, despite significant improvements in several CVD risk factors,<sup>133</sup> and similar results were seen in an RCT involving diabetic patients, randomly assigned either to usual care or slow diaphragmatic breathing.<sup>69</sup> No change in BP in diabetic patients was also reported in another RCT that compared an integrated yoga group with poor compliance to a waitlist control group.<sup>102</sup> Three further RCTS showed no change in BP in normotensive participants with mild to moderate stress,<sup>134</sup> and another RCT reported no change in BP after 1 year for 35 hypertensive patients who randomly received either 8 weeks of relaxation training or nonspecific counseling.<sup>135</sup> No change in BP with yoga was also reported in a 20-week study involving 60 HIV patients<sup>136</sup> and a 10-week
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Chapter 5

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study involving 26 metabolic syndrome individuals randomly assigned to yoga or usual care.111

Many different yoga practices and styles can be adapted or individualized by teachers and practitioners, yet a common element of these practices appears to be the practical application of mind-body integration with the use of the breath as a focus for the link between mind and body. Yoga practices generally lead to a calm, quiet, hypometabolic, meditative state associated with autonomic balance and characterized by positive physiological changes and improved cardio, circulatory, and respiratory function. Therefore, yoga may influence BP through reducing the stress response, increasing parasympathetic activation, and altering baroreceptor sensitivity.

While a large number of published studies have been published, the authors found a great heterogeneity of study designs and yoga practices in the studies examined, and most studies were of poor methodological quality, with small sample sizes and relatively short durations. While 46 RCTs were reviewed, only 4 of these used a placebo group,144,145,146,147 with most using active or no-intervention controls. Furthermore, few studies of yoga and BP involved long-term follow-up, with only 13 studies being of at least 6 months in duration,149,150,151,152,153,154,155,156,157,158,159,160,161,162 and 4 studies over 1 year,152,153,154,155 and 2 studies over 3 years.156,157

A number of specific yoga practices, such as ANB,158 yogic relaxation,159 and slow breathing160,161 have been shown in experimental laboratory studies to have specific effects on BP. It is not yet clear, however, which aspects of yoga, if any, are more important in reducing BP in specific populations, and research into yoga and HPT is hampered by a lack of standardized practices that are specifically designed as a therapy for HPT. Thus, while the use of equipment such as the RESPERATE and biofeedback devices have standardized some practices, and attempts have occurred to standardize yoga practices for different populations, such as silver yoga, the vast array of different practices impedes rigorous reporting and standardization of clinical interventions.

The heterogeneity of yoga practices and lack of standardized research make it difficult to formulate clinical guidelines or prescriptions involving yoga. This difficulty is acknowledged in the guidelines of the British Hypertension Society, which state that “interventions to reduce stress management, meditation, yoga, cognitive therapies, breathing exercises, and biofeedback have been shown to result in short-term reductions in BP, but the interventions studied have been so varied, it is difficult to be prescriptive with regard to an effective strategy.”7,8

The lack of long-term studies, standardized protocols, and conclusive results from meta-analyses has resulted in stress reduction strategies, such as yoga and meditation, being omitted from clinical guidelines on HPT.7,8,10,11 Thus, while these guidelines discuss the importance of lifestyle modification for all hypertensive patients, they focus on aerobic exercise, dietary control, weight reduction, smoking cessation, alcohol reduction, and sodium restriction and do not mention yoga, relaxation, or other stress reduction practices. The Canadian Hypertension Education Program does recommend stress management in the form of cognitive behavioral interventions in hypertensive individuals in whom BP elevation is due to stress but does not consider yoga as a stress management strategy.7

CONCLUSION

Yoga practices have been show to be effective in reducing BP in normotensive and hypertensive populations and to be effective as an adjunct therapy in reducing antihypertensive medication use. While many studies on yoga and HPT have been published, most are of poor methodological quality, with small sample sizes and relatively short durations. It appears that yoga is most commonly used as a spiritual and personal development path rather than as a therapy for specific medical conditions, and this has resulted in many different yoga practices being used. The lack of long-term studies, standardized protocols, and conclusive results from meta-analyses makes it difficult to recommend any specific yoga practice for HPT and this has resulted in stress reduction strategies, such as yoga and meditation, being omitted from clinical HPT guidelines. A lack of yoga training and instruction standards also makes it difficult for people to access standardized yoga instruction and primary care physicians may be reluctant to recommended yoga for their patients with HPT if they cannot ensure the quality or relevance of particular yoga practices. Future research needs to focus on high-quality clinical trials with standardized yoga practices and long-term follow-up, together with studies on the mechanisms of action of different practices.

REFERENCES

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CHAPTER 6
Oxygen Consumption Changes with Yoga Practices: A Systematic Review

Tyagi A, Cohen M, 2013, Journal of Evidence-Based Complementary & Alternative Medicine, 18(4); 290- 308

Introduction

Oxygen consumption (OC) varies with physical and mental activities as well as pathological conditions. Although there is a strong relationship between yoga and metabolic parameters, the relationship between yoga and OC has yet not been reviewed. This systematic review with 58 published studies reported that yoga has profound effect on OC.
Chapter 6

Oxygen Consumption Changes with Yoga Practices: A Systematic Review

Anupama Tyagi, MA¹ and Marc Cohen, PhD, MBBS (Hons)¹

Abstract
Oxygen consumption varies with physical and mental activity as well as pathological conditions. Although there is a strong relationship between yoga and metabolic parameters, the relationship between yoga and oxygen consumption has not yet been formally reviewed. This systematic review attempted to include all studies of yoga that also measured oxygen consumption or metabolic rate as an outcome. A total of 58 studies were located involving between 1 and 104 subjects (average 21). The studies were generally of poor methodological quality and demonstrated great heterogeneity with different experimental designs, yoga practices, time periods, and small sample sizes. Studies report yoga practices to have profound metabolic effects producing both increased and decreased oxygen consumption, ranging from 383% increase with cobra pose to 40% decrease with meditation. Compared to nonpractitioners, baseline oxygen consumption is reported to be up to 15% less in regular yoga practitioners, and regular yoga practice is reported to have a training effect, with oxygen consumption during submaximal exercise decreasing by 36% after 3 months. Yoga breathing practices emphasize breathing patterns and retention ratios as well as unilateral nostril breathing, and these factors appear critical in influencing oxygen consumption. A number of studies report extraordinary volitional control over metabolism in advanced yoga practitioners who appear to be able to survive extended periods in airtight pits and to exceed the limits of normal human endurance. More rigorous research with standardized practices is required to determine the mechanisms of yoga’s metabolic effects and the relevance of yoga practices in different clinical populations.

Keywords
yoga, meditation, pranayama, metabolic rate/cost, oxygen consumption, energy expenditure

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Introduction
Human metabolism is the result of continuous anabolic and catabolic processes that maintain homeostasis and sustain life. Metabolic pathways include a complex network of nutritional, neuronal, and humoral inputs that are integrated by the central and autonomic nervous systems through pathways that monitor and maintain physiological functioning. All metabolic processes generate heat and are ultimately dependent on the expenditure of energy via consumption of oxygen, which drives oxidative phosphorylation.

Energy expenditure is a directly related to metabolic rate and oxygen consumption, and these terms are often used interchangeably. Monitoring oxygen consumption has received a great deal of interest in determining oxygen delivery to tissues, cardiopulmonary function, and metabolic response to activity. Assessment of oxygen consumption is used in determining energy requirements for healthy lifestyles, exercise programs, and critically ill patients. Oxygen consumption is reported to increase with adaption to physiological stress and pathology. The measurement of energy expenditure can be performed via direct calorimetry, which measures heat loss using insulated chambers, or via indirect calorimetry, which directly measures oxygen consumption through respiratory gas exchange. Direct calorimetry is not frequently used as it is complex, does not accurately measure rapid changes in metabolism, and requires significant expertise and elaborate equipment including specially constructed chambers. Indirect calorimetry is the most commonly used technique for measuring energy expenditure and can be used to measure the substrate of metabolism as well as oxygen consumption, which can be expressed in terms of VO2 (absolute oxygen consumption), VO2·kcal/min (relative oxygen consumption), and MET (metabolic equivalent task).

Oxygen Consumption, Stress, and Pathology
Oxygen consumption is maximal during intense physical activity and lowest during basal or resting conditions and higher
oxygen consumption is associated with psychological and physiological activity, stress, pathology, and accelerated aging. Oxygen consumption has also been found to increase with activities such as mental arithmetic and playing video games, as well as with psychological distress and anxiety. A growing body of research further suggests that oxygen consumption is higher in various pathological conditions, including congestive heart failure, locomotor impairment, HIV, chronic obstructive pulmonary disease, insomnia, and congestive heart failure. Oxygen consumption has also been found to increase with features of metabolic syndrome, including obesity, type 2 diabetes, and hypertension.

The measurement of oxygen consumption can provide insights into overall homeostatic balance and response to stress, which are mediated through multiple pathways under the control of the autonomic nervous system and the hypothalamus. The sympathetic nervous system is involved in rapidly mobilizing vital physiological functions via sympathetic–adrenal–medullary pathways in response to acute stress, which serves to increase oxygen consumption. Repeated or chronic stressful stimuli may lead to changes in the hypothalamic–adrenal–pituitary axis, leading to a sustained stress response involving cognitive, emotional, endocrine, and immune system changes.

The parasympathetic nervous system provides a counter to the stress response and reduces oxygen consumption by activating the so-called relaxation response, which serves to reduce physiological arousal and induce a hypometabolic state mediated via enhanced vagal activity. Such hypometabolic states are suggested to enhance survival in plants and animals by facilitating restorative and repair functions.

Yoga, Stress, and Metabolism

Mind–body practices that induce relaxation have been traditionally used by people across cultures to improve health and serve as a path for spiritual awakening. Yoga is an ancient mind–body approach that combines the practice of postures (asana), breathing (pranayama), and meditation (dhyana) with the aim of achieving an effortless state of harmony (samadhi).

Yoga postures include both static and dynamic postures that are designed to attune the body to a stable state suitable for meditation. Yoga breathing includes a range of practices such as Bhastrika (bellows breath), Ujjayi (victorious breath), Kapalbhati (lustrous cranium), and unilateral nostril breathing, which can be performed at different rates (reported as breath/minute) and with different retention periods and patterns that involve either internal retention (inspiration–retention–expiration) or external retention (expiration–retention–inspiration). The yogic state of meditation is characterized by decreased oxygen consumption and cardiovascular activity and has been shown to elicit the relaxation response. This meditative state, which is distinct from rest, physical relaxation, and sleep, may be voluntarily induced, even while performing fixed physiological workloads.

The ability of yoga to induce relaxation and relieve stress has been widely reported, and there are reports of yoga practices reducing acute, chronic, and posttraumatic stress. For example, yoga is reported to relieve workplace stress and examination stress, and stress-induced inflammation. Yoga practices have also been reported to improve many clinical conditions such as anxiety, depression, negative mood states, PTSD symptoms in war veterans, tsunami survivors, hurricane refugees, and flood survivors. Furthermore, 2 reviews, one involving 35 clinical studies and the other 8 controlled trials of healthy adults, acknowledge the promising role of yoga in reducing stress. Li et al also suggest yoga as a potential adjunct to pharmacologic therapy for patients with stress and anxiety. There are further studies to suggest that regular yoga practice reduces physiological and metabolic activity under normal conditions. Compared to nonpractitioners, regular yoga practitioners have been found to have lowered resting heart rate, blood pressure, heart rate, and metabolic rate. Yoga has also been found to improve all features of metabolic syndrome, including obesity, hyperlipidemia, hyperglycemia, and hypertension, with 3 separate randomized controlled trials demonstrating benefits of yoga in metabolic syndrome patients.

While there seems to be a strong relationship between yoga and metabolic parameters, the relationship between yoga and oxygen consumption has not been formally reviewed. The objective of this article is to systematically review previous research exploring the relationship between yoga and oxygen consumption and explore the impact that different yoga practices have on oxygen consumption in different populations.

Methodology

For this systematic review, a comprehensive search of multiple databases including Scopus, PUBMED, PSYCHINFO, CINAHL, Science Direct database was conducted, and a separate search was conducted in Indian medical journals through IndMed, which indexes more than 100 prominent Indian scientific journals. Similarly, a search was performed of Yoga Mimamsa, which includes published yoga research literature dating back from 1920 not listed in the above databases. The archives of the International Journal of Yoga were also searched, along with the reference citations from all full-text articles identified. The primary search terms included Yoga, pranayama, yoga nidra, breathing, relaxation, meditation, Transcendental meditation, Brahmakumari meditation, Raj Yoga meditation, On meditation, mantra meditation, Sahaj Yoga meditation, cyclic meditation, and Kundalini yoga, Kriya yoga, and Sudarshan Kriya along with keywords oxygen consumption, energy expenditure, metabolic cost, and metabolic rate.

All studies that had oxygen consumption (at resting, during yoga intervention, or during physical exercise in which yoga included in the intervention) as an outcome were included in the systematic review. The search was performed for articles published up to December 2012 and was not otherwise restricted by date or study population. The review included studies that examined a range of yoga practices including asana and/or integrative yoga, breathing, meditation and yoga relaxation practices used either alone or as an integrated practice. The studies were excluded if they were not in English (n = 4), unobtainable (n = 5), in press (n = 8), or only documented study protocol (n = 5). Studies were also excluded if they only involved
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Figure 1. Flow chart of study search and included studies.

mediation (religious or nonreligious) and relaxation practices that are not directly associated with yoga such as Zen/Zen Buddhist meditation, Vipassana Meditation, Tantric yoga, Qigong, relaxation response, progressive muscle relaxation, and autogenic relaxation. However, it was beyond the scope of this systematic review to collect and synthesize clinical outcomes other than oxygen consumption or critically assess the methodological quality of all studies. The selection of relevant studies is shown in Figure 1, and the results, including their statistical significance, are noted in the relevant text and tables.

Results

A total of 58 studies of oxygen consumption and yoga practices were extracted (Figure 1). These studies involved between 1 and 104 subjects (average 21) and demonstrated great heterogeneity with many different experimental designs, yoga practices, and time periods. Extracted studies, which were categorized according to the type of intervention (pranayama practice, meditation/relaxation, integrated yoga/asana practice, integrated yoga with physical activity), are presented in Tables 1 to 4, which also include information about study design.

Of the total studies, 35 studies were published from India,70,71,85–117 15 from the United States,118–132 2 from the United Kingdom, 133,134 and 1 each from Mexico, 135 New Zealand, 136 Thailand, 137 Brazil, 138 Japan, 139 and Sweden. 140 Most studies reported assessing oxygen consumption using indirect calorimetry techniques, whether through open circuit, closed circuit, bag system, or respiratory chamber method. Some studies derived oxygen consumption through the standard equations, that is, oxygen consumption was predicted through regression equation with measures of heart rate and oxygen consumption of submaximal exercise, 98 while VO2 max was predicted through achieved workload and using standard formula from the American College of Sports and Medicine 116,130. Oxygen consumption was reported to both increase and decrease with different yoga practices. Increases in oxygen consumption ranged from 7.7% with Ujjayi breathing to 383% during cobra pose (Tables 1 and 3). Studies also report decreases in oxygen consumption, with slow yoga breathing techniques and meditation practices ranging from a 3.7% decrease during Om meditation to a 40% decrease in an advanced yoga during meditation in an airtight pit (Table 2). Basal oxygen consumption is also
### Table 1. Summary of Studies Reporting Changes in Oxygen Consumption With Pranayama Practice(s).

<table>
<thead>
<tr>
<th>Study Reference</th>
<th>Population</th>
<th>Study Design</th>
<th>Intervention</th>
<th>Comparators</th>
<th>Metabolic Measures</th>
<th>Cardiorespiratory and Other Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myneni et al (2000)</td>
<td>Advanced male yoga practitioner (n = 1)</td>
<td>Single practice on a single occasion</td>
<td>Ujaya breathing at 3 breath/min</td>
<td>Ujaya vs post-pranayama</td>
<td>of 10% in OC during Ujaya</td>
<td>HR during breathing session 9% higher compared to post</td>
</tr>
<tr>
<td>Myles and Bahana (1994)</td>
<td>Male yoga practitioner (n = 1)</td>
<td>Multiple practices on a single occasion</td>
<td>Ujaya, Kapihliti, and Bhastrik breathing</td>
<td>Siting and reclined postures vs Pranayama</td>
<td>of 31%, 35%, and 30% in OC of during pranayama compared to sitting and 3%, 4%, and 36% compared to reclined</td>
<td></td>
</tr>
<tr>
<td>Myles (1969)</td>
<td>Male yoga practitioner (n = 1)</td>
<td>Multiple practices on multiple occasions</td>
<td>Ujaya (40 seconds retention at 1.26 breath/min; Kapihliti (12.5 and 60 breath/min); Bhastrik (21 and 1.3 breath/min)</td>
<td>Baseline versus pranayama practices</td>
<td>of 25% in OC during Ujaya, 12% during Kapihliti, and 19% during Bhastrik</td>
<td></td>
</tr>
<tr>
<td>Rao (1968)</td>
<td>Male yoga practitioner (n = 1)</td>
<td>Single practice on 2 occasions</td>
<td>Ujaya breathing at 2 different altitudes 520 m and 1880 m</td>
<td>Baseline versus Ujaya breathing at low altitude; Baseline breathing versus Ujaya at high altitude</td>
<td>of 7.7% in OC during Ujaya with breath rate 1.5 breath/min at low altitude</td>
<td></td>
</tr>
<tr>
<td>Karambelkar et al (1982)</td>
<td>Male yoga practitioners (n = 8)</td>
<td>Multiple practices on a single occasion</td>
<td>Kapihliti at 120 breath/min and hyperventilation breathing at 1.6 breath/min</td>
<td>Baseline breathing versus Kapihliti breathing and hyperventilatory breathing</td>
<td>of 56% in OC and 1% of 23% in CO2 exhalation during Kapihliti</td>
<td></td>
</tr>
<tr>
<td>Karambelkar et al (1982)</td>
<td>Male yoga practitioners (n = 3)</td>
<td>Multiple practices on a single occasion</td>
<td>Bhastrik with internal retention (E.R.I = 8.2; 16) and external retention (E.R.I = 3.00; 10)</td>
<td>Baseline versus Bhastrik breathing with internal retention and external retention</td>
<td>of 13% in OC and 1% of 37% in CO2 exhalation during hyperventilatory breathing</td>
<td></td>
</tr>
<tr>
<td>Frostell et al (1983)</td>
<td>Experienced male yoga practitioners (n = 3)</td>
<td>Single practice on a single occasion</td>
<td>Bhastrik at 232 breath/min</td>
<td>Baseline versus pranayama</td>
<td>of 52% in MV and 25% in VT during hyperventilatory breathing</td>
<td></td>
</tr>
<tr>
<td>Karambelkar and Bhole (1988)</td>
<td>Male yoga practitioners (n = 7)</td>
<td>Multiple practices on a single occasion</td>
<td>Kapihliti at 120 breath/min</td>
<td>Pranayama practices vs baseline</td>
<td>of 2% in OC and 1% of 38% in CO2 exhalation during Kapihliti</td>
<td></td>
</tr>
<tr>
<td>Karambelkar et al (1983)</td>
<td>Male yoga practitioners (n = 3)</td>
<td>Multiple practices on a single occasion</td>
<td>Bhastrik with internal retention (E.R.I = 3.00; 10) and Ujaya with external retention (E.R.I = 6.12; 12)</td>
<td>Pranayama practices vs baseline</td>
<td>of 4% in OC and 2% of 3% in CO2 exhalation during Bhastrika</td>
<td></td>
</tr>
</tbody>
</table>

(continued)
<table>
<thead>
<tr>
<th>Study Reference</th>
<th>Population</th>
<th>Study Design</th>
<th>Intervention</th>
<th>Comparators</th>
<th>Metabolic Measures</th>
<th>Cardiorespiratory Other Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karambelkar et al</td>
<td>Regular and beginner male</td>
<td>Single practice on</td>
<td>Ujjayi breathing with internal (TRE = 0.32:1)</td>
<td>Pronayama versus baseline</td>
<td>Significant: of 21% in OC and of 34% in OC was observed during the same practices</td>
<td>of 26% in OC and of 25% in CO&lt;sub&gt;2&lt;/sub&gt; exhalation during pronayama compared to baseline</td>
</tr>
<tr>
<td>(1993)&lt;sup&gt;16&lt;/sup&gt;</td>
<td>yoga practitioners (n = 9)</td>
<td>a single occasion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Danucalov et al</td>
<td>Experienced yoga practitioners</td>
<td>Multiple practices on</td>
<td>Slow paced pronayama with extended period of retention (internal retention: TRE = 1:12)</td>
<td>Pronayama versus meditation and</td>
<td></td>
<td>of 35% in OC during mediation compared to baseline</td>
</tr>
<tr>
<td>(2008)&lt;sup&gt;18&lt;/sup&gt;</td>
<td>with &gt;3 years of experience (n = 9)</td>
<td>a single occasion</td>
<td></td>
<td>baseline</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telles and</td>
<td>Male yoga practitioners; short</td>
<td>Multiple practices on</td>
<td>Ujjayi breathing with 2 different internal retention periods: short</td>
<td>Baseline versus Pronayama</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Desaiju (1999)&lt;sup&gt;12&lt;/sup&gt;</td>
<td>breath retention group (n = 5) and long</td>
<td>a single occasion</td>
<td>retention (TRE = 1:9:4) and long retention (TRE = 1:1:1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telles et al</td>
<td>Male yoga practitioners (n = 12)</td>
<td>Multiple practices on</td>
<td>RNB session and normal breathing session (each session of 45 minutes on different days)</td>
<td>Baseline breathing versus post-RNB session and post-RNB session</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1996)&lt;sup&gt;13&lt;/sup&gt;</td>
<td>with &gt;3 years of experience (n = 12)</td>
<td>1 occasions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prasad et al</td>
<td>Male yoga practitioners;</td>
<td>Multiple practices on</td>
<td>ANB for 30 minutes, treadmill walk at 3 km/h (1.9 mph) for 30 minutes, and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2001)&lt;sup&gt;14&lt;/sup&gt;</td>
<td>&gt;3 years of experience (n = 12)</td>
<td>a single occasion</td>
<td>treadmill walk 1.5 km in 30 min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ray et al</td>
<td>Male yoga practitioners;</td>
<td>Multiple practices on</td>
<td>Hatha yoga session comprising variety of yoga static postures interspersed with</td>
<td>Siting rest (Sukhasana) versus each individual pronayama versus rest sitting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2011)&lt;sup&gt;15&lt;/sup&gt;</td>
<td>&gt;3 years of experience (n = 20)</td>
<td>1 occasions</td>
<td>Shavasana and meditation practices; V&lt;sub&gt;Y&lt;/sub&gt;O&lt;sub&gt;max&lt;/sub&gt; session (each session on different days)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telles et al</td>
<td>Male yoga practitioners (n = 48)</td>
<td>Four weeks regular</td>
<td>Random assignment to RNB (n = 12), LNB (n = 12), or ANB (n = 24); each assigned breathing 4 times daily for 4 weeks</td>
<td>Post-pronayama intervention for versus preintervention</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1999)&lt;sup&gt;16&lt;/sup&gt;</td>
<td>practice in multiple groups</td>
<td>practice</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: OC, oxygen consumption; HR, heart rate; CO<sub>2</sub>, carbon dioxide; MV, minute ventilation; VT, tidal volume; TRE, inspiration–retention–expiration; ERI, expiration–retention–inspiration; BPM, beats per minute; CO, cardiac output; RNB, right nostril breathing; SBP, systolic blood pressure; GSR, galvanic skin resistance; ANB, alternate nostril breathing; LNB, left nostril breathing.
### Table 2. Summary of Studies Reporting Changes in Oxygen Consumption With Mediation/Relaxation Practice(s).

<table>
<thead>
<tr>
<th>Study Reference</th>
<th>Population</th>
<th>Study Design</th>
<th>Intervention Description</th>
<th>Comparators</th>
<th>Metabolic Measures</th>
<th>Cardiorespiratory and Other Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anand et al (1966)</td>
<td>Experienced male yoga practitioners (n = 1)</td>
<td>Single practice on 2 occasions</td>
<td>Stay in air-tight box during 2 different days of 10 hours each</td>
<td>Baseline (basal) versus stay in box</td>
<td>37.4% and 32% in OC during 2 different sessions</td>
<td>HR increase up to 15 BPM during session; HR rose only when ambient O2 declined to 15% and CO2 reached to 7% in the pit; OC declined to 35% of BMR (195 L/h) on one occasion</td>
</tr>
<tr>
<td>Karambelkar et al (1968)</td>
<td>Experienced male yoga practitioners (n = 4)</td>
<td>Single practice on a single occasion</td>
<td>Stay in air-tight pit &gt;12 hours and up to 18 hours</td>
<td>Baseline (basal) versus stay in pit</td>
<td>OC during stay in pit lesser than basal condition; subjects remained in pit until ambient O2 declined to 12% and CO2 rose to 7%; The maximum stay in pit for 18 hours when ambient CO2 was 7.7% and O2 11.6%</td>
<td>HR and BR rose when ambient CO2 reached to 5% in pit</td>
</tr>
<tr>
<td>Craig Hillel et al (1977)</td>
<td>Yogi male (proficient in kundalini yoga (subterrestrial stay) (n = 1)</td>
<td>Single practice on a single occasion</td>
<td>Stay in subterranean chamber for 4 hours</td>
<td>Baseline (basal) versus stay in pit</td>
<td>45% in OC during the stay in chamber compared to basal baseline measured through gas volume meter</td>
<td></td>
</tr>
<tr>
<td>Wallace (1970)</td>
<td>Meditators with &gt;6 months experience (n = 15)</td>
<td>Single practice on a single occasion</td>
<td>Transcendental meditation (TM); 30 minutes meditation session</td>
<td>Baseline versus meditation</td>
<td>23% in OC during meditation compared to baseline</td>
<td></td>
</tr>
<tr>
<td>Wallace et al (1971)</td>
<td>Meditators with mean 29.4 months experience (n = 30)</td>
<td>Single practice on a single occasion</td>
<td>Transcendental meditation; 30 minutes meditation session</td>
<td>Baseline versus meditation</td>
<td>17% in OC (P &lt; .005) and 15% in CO2 (P &lt; .000) during meditation</td>
<td></td>
</tr>
<tr>
<td>Benson et al (1975)</td>
<td>Meditators with &lt;1 year experience (n = 13)</td>
<td>Single practice on a single occasion</td>
<td>Transcendental meditation; 30 minutes meditation session</td>
<td>Baseline versus meditation</td>
<td>5% in OC (P &lt; .05) and 6% in CO2 (P &lt; .001) during meditation</td>
<td></td>
</tr>
<tr>
<td>Dimicco et al (2008)</td>
<td>Experienced yogi practitioners with &gt;1 years experience (n = 9)</td>
<td>Multiple practices on a single occasion</td>
<td>Transcendental meditation and pranayama</td>
<td>Baseline versus meditation and pranayama</td>
<td>31% in OC (P &lt; .05) during meditation compared to baseline; 45% in OC during meditation compared to pranayama</td>
<td></td>
</tr>
<tr>
<td>Fenwick et al (1977)</td>
<td>Meditators with &gt;22 months experience (n = 11) and nonmeditators (n = 8)</td>
<td>Multiple practices on a single occasion</td>
<td>Transcendental meditation (TM) and listening music</td>
<td>Baseline versus meditation and listening to music in meditators and nonmeditators; comparison between groups</td>
<td>Nonsignificant drop in OC and CO2 during meditation in meditators and nonmeditators; nonsignificant difference in reduction of OC between meditation and listening music; nonsignificant difference between groups in OC during TM 4%, during PMR 3.5%, in regular practitioners, and 8.3% in nonpractitioners (P &lt; 0.01) compared to control groups.</td>
<td>HR during meditation (P &lt; 0.01)</td>
</tr>
<tr>
<td>Warrenburg et al (1980)</td>
<td>Regular meditators with &lt;6 years’ experience (n = 9); regular relaxation practitioners with mean 6.4 years’ experience (n = 1); nonpractitioners (n = 7)</td>
<td>Multiple practices on a single occasion</td>
<td>Transcendental meditation (TM) progressive muscle relaxation (PMR); nonpractitioner—listening music</td>
<td>Control periods of closed eyes and reading book versus intervention; comparison between groups</td>
<td></td>
<td>No evidence of hypometabolism during meditation in both the groups</td>
</tr>
</tbody>
</table>

(continued)
Table 1. (continued)

<table>
<thead>
<tr>
<th>Study Reference</th>
<th>Population</th>
<th>Study Design</th>
<th>Intervention</th>
<th>Comparators</th>
<th>Metabolic Measures</th>
<th>Cardiorespiratory and Other Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keasterson and Clinch (1989)</td>
<td>Advanced meditators with mean 28 years experience (n = 33); nonmeditators (n = 10)</td>
<td>Multiple practices on a single occasion</td>
<td>Transcendental meditation (TM); nonmeditators—eyes closed relaxation</td>
<td>Baseline versus intervention: comparison between the groups</td>
<td>Similar significant drop in OC (P &lt; .001) during TM and relaxation; nonsignificant difference between groups</td>
<td>No traces of hypometabolism in either group</td>
</tr>
<tr>
<td>Telles et al. (1995)</td>
<td>Male meditators &gt;5 years experience (n = 7)</td>
<td>Multiple practices on 2 occasions</td>
<td>Aum meditation session and sitting relaxed session (each session of 20 minutes on different days)</td>
<td>Baseline rest versus postmeditation and eyes closed relaxation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vempati and Telles (1999)</td>
<td>Male yoga practitioners with mean 22.9 months experience (n = 40)</td>
<td>Multiple practices on 2 occasions</td>
<td>Yoga-based hatha yoga relaxation and supine rest (each session of 10 minutes on different days)</td>
<td>Baseline rest versus postyoga relaxation and supine rest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vempati and Telles (2002)</td>
<td>Male yoga practitioners with mean 30.2 months experience (n = 35)</td>
<td>Multiple practices on 2 occasions</td>
<td>Yoga-based guided relaxation session and supine rest session (each session of 10 minutes on different days)</td>
<td>Baseline rest versus postyoga relaxation and supine rest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ray et al. (2011)</td>
<td>Male yoga practitioners &gt;6 years' experience (n = 20)</td>
<td>Multiple practices on 2 occasions</td>
<td>Hatha yoga session—comprising variety of yoga asanas practiced interspersed with Shavasana, pranayama; VO&lt;sub&gt;2max&lt;/sub&gt; session (each session on different days)</td>
<td>Rest sitting (Sukhasana) versus meditation and Aum meditation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thiel (1983)</td>
<td>Healthy nonpractitioner males (n = 33)</td>
<td>15 weeks of regular practice, multiple group</td>
<td>Meditation group (n = 21); transcendental meditation, relaxation group (n = 18); progressive muscle relaxation</td>
<td>Baseline versus immediately after practice of first session and then after 5, 10, and 13 weeks apart</td>
<td>Meditators displayed greater reduction in OC during the practice; reduction in OC more prominent in relaxation over time of 15 weeks compared to meditation</td>
<td>Reduction in HR in mediation group prominent (P &lt; .05) compared to relaxation over time</td>
</tr>
</tbody>
</table>

Abbreviations: OC, oxygen consumption; HR, heart rate; BPM, beats per minute; CO<sub>2</sub>, carbon dioxide; BMR, basal metabolic rate; BR, breath rate; GSR, galvanic skin resistance; LF/E, inspiration—expiration; LF, low frequency; HF, high frequency.
reported to be up to 15% less in regular yoga practitioners compared to nonpractitioners, and oxygen consumption during submaximal exercise is reported to decrease by 36% after 3 months of regular yoga practice (Table 4).

Pranayama Practices and Oxygen Consumption

Table 1 summarizes 16 pranayama (yogic breathing) studies that include a total of 143 participants and report wide variations in oxygen consumption. While oxygen consumption was seen to increase with most breathing practices performed at both fast (232 breath/min) and slow (1 breath/min) rates (Table 1), a decrease in oxygen consumption from rest was also seen in some slow breathing practices. The highest increase in oxygen consumption was seen with extremely rapid Bhasrika breathing, which involves rapid, forced thoracic inhalation and exhalation. When Caheerika was performed at a rate of 232 breath/min by 3 advanced practitioners, oxygen consumption was reportedly increased by 206%, and across all groups, oxygen consumption increased by 30%, 24%, 22%, 17%, and 15% for advanced practitioners and 12% for intermediate practitioners. Increases in oxygen consumption from 12% to 50% are also reported with Kapalabhati breathing, which involves forced rapid exhalation. Unilateral nostril breathing (alternate nostril breathing, right nostril breathing, and left nostril breathing) are reported to increase oxygen consumption with a 150% increase during alternate nostril breathing, and increases of 37% to 18% reported immediately after alternate nostril breathing, right nostril breathing, and left nostril breathing practices.

Oxygen consumption is also reported to increase with some slow yoga breathing. Ujjayi breathing, which involves controlled slow, deep breathing with long inhalation and exhalation and gentle contraction of the glottis creating a soft snoring sound, has been consistently reported to increase oxygen consumption, even at extremely slow rates. An increase of 19% is reported in a single advanced practitioner while practicing Ujjayi at a rate of 1 breath/min, while further studies report increases in oxygen consumption of 25% and 52% during Ujjayi with a 40-second retention ratio of 1:2:1. An increase in oxygen consumption was also reported with Ujjayi performed at different altitudes, with a 16% greater oxygen consumption observed in a single practitioner at 3200 m elevation practicing Ujjayi breathing at 3 breath/min compared to practicing Ujjayi breathing at 520 m elevation at 1.5 breath/min. An increase in oxygen consumption to 17% has also been reported in advance yoga practitioners during slow paced breathing with inspiration-retention-expiration ratio of 1:4:2.

Only 4 studies (Table 1) report decreases in oxygen consumption with pranayama. A decrease in oxygen consumption of 4%, 21%, and 19% is reported during slow Ujjayi breathing at rates of 2 breath/min, 1.4 breath/min, or with an inspiration-retention-expiration ratio of 1:4:4. A decrease in oxygen consumption of 16% is also reported during Bhasrika breathing at 12 breath/min.

Yoga Meditation, Relaxation Practices, and Oxygen Consumption

Table 2 summarizes 15 studies with a total of 310 participants that consistently report reduced oxygen consumption during different meditation and relaxation practices. Two studies of yogic relaxation practices report 25.2% and 23% reductions in oxygen consumption compared to rest. Transcendental meditation is also reported to produce reductions of oxygen consumption from rest, with 3 separate studies reporting reductions of 20%, 17%, and 5%. Reductions in oxygen consumption from rest of 15% and 3.7% are also reported during 2 to 3 minutes of meditation.

Studies comparing meditation with non-yogic relaxation techniques shows modest or no difference between interventions. Four studies report no difference in oxygen consumption between groups practicing Transcendental and those practicing a control relaxation intervention, while a further study reports no significant reduction in oxygen consumption from baseline rest during either after Om meditation or relaxed sitting, despite reported reductions in heart rate and increases in galvanic skin response.

Among the studies reporting reductions in oxygen consumption, the most dramatic reductions were seen in 2 studies involving advance yoga practitioners, with one study reporting reductions in oxygen consumption of 40% below rest during a 4-hour stay in an air tight subterranean chamber and another study reporting reductions of 32% and 37% below rest during 2 separate 10-hour stays in an air tight box. Reductions in oxygen consumption of around 35% below rest are also reported during meditation in a group of experienced yogis. An early study with 3 advanced yoga practitioners further reports that during a prolonged stay in an air tight pit, advanced meditators could tolerate ambient oxygen levels of 12.2% and carbon dioxide levels of 7.3%.

Asana/Integrated Yoga Practices and Oxygen Consumption

Table 3 presents 13 studies with a total of 272 subjects that consistently report increases in oxygen consumption with different yoga asanas (postures). The most dramatic increase was seen in a group of 21 male practitioners who experienced a 383% increase in oxygen consumption while performing coban pose. Increases in oxygen consumption were also reported with warrior III pose (300%), plough pose (2160%), hero pose (159%), headstand pose (68%), and accomplished pose (27%).

Over the course of a yoga session, oxygen consumption has been reported to increase by 100% with Ashtanga yoga, 114% with Hatha yoga, 133% with Thai yoga, and 144% with Vinyasa yoga. Three studies have examined oxygen consumption during Sun Salutation (a dynamic sequence
### Table 3: Summary of Studies Reporting Changes in Oxygen Consumption With Asana, Integrated Practice(s).

<table>
<thead>
<tr>
<th>Study Reference</th>
<th>Population</th>
<th>Study Design</th>
<th>Intervention</th>
<th>Comparator 1</th>
<th>Comparator 2</th>
<th>Metabolic Measures 1</th>
<th>Cardiorespiratory and Other Measures 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rao (1962)</td>
<td>Male yoga practitioners (n = 6)</td>
<td>Single practice on a single occasion</td>
<td>Head stand posture</td>
<td>Baseline, recumbent and standing erect posture.</td>
<td>Vrksasana</td>
<td></td>
<td>68% and 48% increase in OC during headstand posture compared to recumbent postures.</td>
</tr>
<tr>
<td>Rai and Ram (1993)</td>
<td>Male yoga practitioners (n = 10)</td>
<td>Single practice on a single occasion</td>
<td>Vrksasana (hero pose); Subgroup 1—resting breath rate &gt; 10 breath/min (n = 6); Subgroup 2—resting breath rate &lt; 5 breath/min (n = 4)</td>
<td>Baseline, recumbent and standing erect posture.</td>
<td>Vrksasana</td>
<td></td>
<td>60% and 43% increase in HR in subgroups 1 and 2, respectively.</td>
</tr>
<tr>
<td>Rai et al (1994)</td>
<td>Male yoga practitioners (n = 10)</td>
<td>Single practice on a single occasion</td>
<td>Siddhasana (accomplished pose); Subgroup 1—resting breath rate &gt; 10 breath/min (n = 6); Subgroup 2—resting breath rate &lt; 5 breath/min (n = 4)</td>
<td>Baseline, recumbent and standing erect posture.</td>
<td>Siddhasana</td>
<td></td>
<td>27% in OC (P &lt; .001) and 31% in CO2 exhalation (P &lt; .01) during Vrksasana compared to recumbent postures.</td>
</tr>
<tr>
<td>Sinha et al (2004)</td>
<td>Male yoga practitioners (n = 10)</td>
<td>Single practice on a single occasion</td>
<td>Sun salutation (SS)—12 dynamic postures preceded and followed by Shavasana</td>
<td>Comparison between each individual posture of SS and Shavasana</td>
<td></td>
<td></td>
<td>13% (P &lt; .01) and 15% (P &lt; .001) in HR in subgroups 1 and 2, respectively.</td>
</tr>
<tr>
<td>Blank (2006)</td>
<td>Female yoga practitioners (n = 15)</td>
<td>Single practice on a single occasion</td>
<td>Vinyasa yoga posture sequences—warm-up, 20 individual postures, and releasing poses with Shavasana</td>
<td>Comparison between each individual posture and postures divided in sets (back arch, inversion, standing, supine, and seated)</td>
<td></td>
<td></td>
<td>73% increase in HR compared to warm-up posture.</td>
</tr>
<tr>
<td>Hughes et al (2007)</td>
<td>Yoga practitioners with &gt; 1 year experience in yoga; 2 males, 28 females (n = 20)</td>
<td>Multiple practices on a single occasion</td>
<td>Hatha yoga session of 56 minutes—Warm-up, sun salutation, and non-sun salutation poses; mild and moderate maximal exercise—treadmill walk at 2 mph and 3 mph</td>
<td>Baseline rest and mild to moderate exercise posture; sun salutation versus non-sun salutation poses</td>
<td></td>
<td></td>
<td>100% in OC (P &lt; .001) during yoga session compared to recumbent poses.</td>
</tr>
<tr>
<td>Tilles et al (2008)</td>
<td>Male yoga practitioner with &gt; 3 months experience (n = 40)</td>
<td>Multiple practices on 2 occasions</td>
<td>Cyclic meditation (CM) session and Shavasana session (each session on different days)</td>
<td>Baseline rest versus postpractice session of CM and Shavasana</td>
<td></td>
<td></td>
<td>12% in OC (P &lt; .001) post-CM, 13% in OC (P &lt; .05) post-Shavasana compared to baseline.</td>
</tr>
<tr>
<td>Sarang and Teles (2006)</td>
<td>Male yoga practitioners with &gt; 3 months experience (n = 50)</td>
<td>Multiple practices on 2 occasions</td>
<td>Cyclic meditation session (CM) divided into 4 phases and Shavasana session (each session on different days)</td>
<td>Baseline rest versus CM session and Shavasana session; baseline rest versus postpractice session of CM and Shavasana</td>
<td></td>
<td></td>
<td>31% in OC (P &lt; .001) during active phase of CM compared to baseline.</td>
</tr>
</tbody>
</table>
Table 3. (continued)

<table>
<thead>
<tr>
<th>Study Reference</th>
<th>Population</th>
<th>Study Design</th>
<th>Intervention</th>
<th>Comparators</th>
<th>Metabolic Measures</th>
<th>Cardiorespiratory and Other Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>DiCarlo et al (1995)</td>
<td>Yoga practitioners with &gt;1 year experience (n = 13)</td>
<td>Multiple practices on 2 occasions</td>
<td>Hatha yoga—12 standing postural sequence session; submaximal exercise session treadmill walk at 4 mph and VO_{2max} session (each session on different days)</td>
<td>Submaximal exercise and VO_{2max} session versus Hatha yoga routine session</td>
<td>OC 36% lower during yoga sequences (P &lt; .05) compared to submaximal exercise in first 8th minute and remained lower during complete session; yoga session 34% of VO_{2max} and submaximal exercise 44% of VO_{2max}</td>
<td>HR 4% higher in during yoga sequence (P &lt; .05) compared to submaximal exercise in 8th minute and remained higher during complete yoga session</td>
</tr>
<tr>
<td>Carroll et al (2003)</td>
<td>Yoga practitioners with &gt;3 months experience (n = 13)</td>
<td>Multiple practices on 2 occasions</td>
<td>Vinyasa yoga sequences and VO_{2max}</td>
<td>VO_{2max} versus Vinyasa yoga</td>
<td>YS session &gt;50% of VO_{2max}</td>
<td>Yoga session &gt;7% of HR_{max}</td>
</tr>
<tr>
<td>Cay et al (2005)</td>
<td>Yoga practitioners with &gt;1 month experience (n = 30); 2 males, 28 females</td>
<td>Multiple practices on 2 occasions</td>
<td>Hatha yoga session—warm-up, sun salutation, sun salutation, and cool down pose; submaximal exercise—treadmill walk at 3.5 mph and VO_{2max} session (each session on different days)</td>
<td>Chair sitting, submaximal exercise and VO_{2max} session versus Hatha yoga session</td>
<td>of 11.4% in OC (P &lt; .05) during yoga session compared to chair sitting; OC 54% lower (P &lt; .05) during yoga session compared to submaximal exercise; yoga session 14.5% and submaximal exercise 44.8% of VO_{2max}; CO 82% higher (P &lt; .05) during sun salutation compared to non-sun salutation</td>
<td></td>
</tr>
<tr>
<td>Biraruk et al (2010)</td>
<td>Middle aged non-yoga practitioners (n = 17)</td>
<td>Multiple practices on 2 occasions</td>
<td>Thai yoga session—warm-up, sitting, standing, and yoga pose; VO_{2max} session (each session on different days)</td>
<td>VO_{2max} session and baseline rest versus Thai yoga session</td>
<td>of 13% during yoga session compared to rest; yoga session 35.5% of VO_{2max}; OC 4% higher (P &lt; .0001) during standing pose compared to sitting</td>
<td></td>
</tr>
<tr>
<td>Ray et al (2011)</td>
<td>Male yogis practitioners with &gt;9 years' experience (n = 20)</td>
<td>Multiple practices on 2 occasions</td>
<td>Hatha yoga session—comprising variety of yoga static postures interspersed with shavasana, pranayama, and meditation practices; VO_{2max} session (each session on different days)</td>
<td>VO_{2max} session and shavasana versus individual yoga static postures</td>
<td>of 16% in OC (P &lt; .05) during plough pose-2; of 15% in OC (P &lt; .05) during bow pose compared to shavasana; Bow, plough-1, plough-2, and shoulder stand pose 26.5%, 25.9%, 14.6%, 22.7%, respectively, of VO_{2max}; shavasana 9.9% of VO_{2max}</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: OC, oxygen consumption; CO_{2}, carbon dioxide; BR, breath rate; HR, heart rate; BPM, beats per minute.
Table 4. Summary of Studies Reporting Changes in Oxygen Consumption With Yoga and Physical Activity.

<table>
<thead>
<tr>
<th>Study Reference</th>
<th>Population</th>
<th>Study Design and Duration</th>
<th>Intervention</th>
<th>Comparisons</th>
<th>Metabolic Measures</th>
<th>Cardiorespiratory and Other Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sagar et al (1975)</td>
<td>Healthy males (n = 38)</td>
<td>Multiple practices on single occasion</td>
<td>6 months of regular lotus posture training (n = 10); resistance training (n = 12); sedentary lifestyle (n = 16)</td>
<td>Comparison between groups during mild and moderate level energetic exercise</td>
<td>At mild-level exercise the OC was lowest in lotus group followed by exercisers and nonexercisers; at moderate-level exercise OC lowest in exercisers followed by lotus and nonexercisers</td>
<td>Progressive increase in OC during sub-maximal exercise (P &lt; 0.05) and 6 months compared to pre-intervention; no significant increase after 1 month</td>
</tr>
<tr>
<td>Blasrager et al (1978)</td>
<td>Healthy non-yoga practitioners (n = 20)</td>
<td>6-Month cohort study of multiple practices</td>
<td>Regular integrated yoga practices</td>
<td>Pre-yoga intervention sub-maximal exercise versus fixed intensity sub-maximal exercise after 1, 3, and 6 months of yoga practice</td>
<td>Non-significant decrease in resting OC</td>
<td></td>
</tr>
<tr>
<td>Joseph et al (1981)</td>
<td>Healthy male non-yoga practitioners (n = 10)</td>
<td>3-Month cohort study of multiple practices</td>
<td>Regular integrated yoga practices</td>
<td>Pre-yoga intervention rest versus post-yoga intervention rest</td>
<td>Non-significant change in resting OC in either gender; of 41% in OC (P &lt; 0.05) during sub-maximal exercise after 20 days and of 36% in OC (P &lt; 0.05) during sub-maximal exercise after 3 months in males only</td>
<td></td>
</tr>
<tr>
<td>Raju et al (1986)</td>
<td>Non-yoga practitioners (n = 12)</td>
<td>3-Month cohort study of multiple practices</td>
<td>Regular integrated yoga practice</td>
<td>Pre-yoga intervention rest versus post-yoga intervention rest; Pre-yoga intervention sub-maximal exercise versus sub-maximal exercise after 20 days and 3 months of yoga practice</td>
<td>Of 17% in VO_{max} (P &lt; 0.05)</td>
<td></td>
</tr>
<tr>
<td>Babu et al (1989)</td>
<td>Healthy non-yoga practitioners (n = 17)</td>
<td>6-Week cohort study of multiple practices</td>
<td>Integrated yoga practice</td>
<td>Pre-yoga intervention VO_{max} versus post-yoga intervention VO_{max}</td>
<td>Of 1% in OC (P &lt; 0.05) per unit of work load; of 21% maximal work load (P &lt; 0.05) in post-yoga intervention compared to pre-yoga intervention</td>
<td></td>
</tr>
<tr>
<td>Raju et al (1997)</td>
<td>Healthy female non-yoga practitioner (n = 6)</td>
<td>4-Week cohort study of multiple practices</td>
<td>Integrated yoga practice</td>
<td>Pre-yoga intervention VO_{max} versus post-yoga intervention VO_{max}</td>
<td>Of 4% in HR (P &lt; 0.05) post-yoga intervention; of 4% in body fat and weight (P &lt; 0.05)</td>
<td></td>
</tr>
<tr>
<td>Tran et al (2001)</td>
<td>Healthy non-yoga practitioners (n = 10)</td>
<td>8-Week cohort study of multiple practices</td>
<td>Integrated yoga session</td>
<td>Pre-yoga intervention VO_{max} versus post-yoga intervention VO_{max}</td>
<td>Increase in HR (P &lt; 0.05) in both groups improvement in lipid profile and blood glucose and BMI (P &lt; 0.05) in both groups</td>
<td></td>
</tr>
<tr>
<td>Ramos-Martinez et al (2011)</td>
<td>Female, middle-aged, and old yoga practitioners with ≥3 years experience (n = 13)</td>
<td>11-Week cohort study of multiple practices</td>
<td>Integrated intensive yoga training (middle-aged practitioners with mean age 43 years; 4: older practitioners with mean age 62 years; 9)</td>
<td>Pre-yoga intervention VO_{max} versus post-yoga intervention VO_{max}</td>
<td>Of 33% in VO_{max} (P &lt; 0.05) in middle-aged group and of 17% in VO_{max} (P &lt; 0.05) in older group</td>
<td></td>
</tr>
<tr>
<td>Raju et al (1994)</td>
<td>Healthy male non-yoga practitioners (n = 28)</td>
<td>24-Month NRCT of multiple practices</td>
<td>Yoga group—Panyam and shiatsu along with regular sports workouts (n = 14); Control—Regular sports workouts (n = 14)</td>
<td>Pre-intervention rest versus post-intervention rest (phases 1 and 2); pre-intervention sub-maximal and maximal exercise versus post-intervention sub-maximal and maximal exercise</td>
<td>Progressive increase in VO_{max} in both groups compared to pre-intervention in yoga group</td>
<td></td>
</tr>
<tr>
<td>Ray et al (2001)</td>
<td>Healthy male non-yoga practitioners (n = 18)</td>
<td>6-Month RCT of multiple practices</td>
<td>Yoga group—integrated yoga practices (n = 17); physical training as part of army program (n = 11)</td>
<td>Pre-intervention VO_{max} versus post-intervention VO_{max}</td>
<td>Of 16% in VO_{max} (P &lt; 0.05) in yoga group; no change in physical training group</td>
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(continued)
<table>
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<tr>
<th>Study Reference</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Nayar et al (1975)</td>
<td>Healthy male non-yoga practitioners (n = 33)</td>
<td>12-Month RCT of multiple practices</td>
<td>Yoga group—integrated yoga with regular physical training (n = 18); Aerobic group—aerobic with regular physical training (n = 17); Control—regular physical training (n = 18)</td>
<td>Pre-intervention rest versus post-intervention rest; pre-intervention submaximal versus post-intervention submaximal exercise</td>
<td>Non-significant changes in O2 at rest in either group; non-significant changes in O2 during submaximal exercise in either group</td>
<td>29% change in vital capacity (P &lt; 0.01) and 5% in FEV1 (P &lt; 0.05) in yoga group; 46% change in breath-held time (P &lt; 0.01) in yoga group</td>
</tr>
<tr>
<td>Salamuny et al (1988)</td>
<td>Healthy male non-yoga practitioners (n = 30)</td>
<td>6-Month RCT of multiple practices</td>
<td>Yoga group—integrated training (n = 15); Physical training (PT) group—running, gym, flexibility and pull-ups (n = 15)</td>
<td>Pre-intervention submaximal exercise versus post-yoga intervention submaximal exercise</td>
<td>5.7% change in O2 (P &lt; 0.05) in yoga group; non-significant change in PT group</td>
<td>7% increase in HR (P &lt; 0.01) in yoga group</td>
</tr>
<tr>
<td>Bowman et al (1997)</td>
<td>Sedentary healthy elderly subjects &gt;62 years (n = 40)</td>
<td>6-Week RCT of multiple practices</td>
<td>Yoga group—integrated yoga (n = 20); Aerobic group—bicycle-based aerobic training (n = 20)</td>
<td>Pre-intervention submaximal exercise versus post-yoga intervention with submaximal exercise</td>
<td>13% change in VO2peak (P &lt; 0.01) in yoga group and 24% change in VO2peak (P &lt; 0.01) in aerobic group</td>
<td>11.6% increase in HR (P &lt; 0.05) in yoga group; no change in aerobic group; no significant change in HR in either group</td>
</tr>
<tr>
<td>Pulles et al (2008)</td>
<td>Patients with congestive heart failure (CHF) (n = 19)</td>
<td>6-Week RCT of multiple practices</td>
<td>Yoga group—integrated yoga practices along with standard medical therapy (n = 9); Control—standard medical therapy with general awareness (n = 10)</td>
<td>Pre-intervention VO2peak versus post-intervention VO2peak</td>
<td>17% change in VO2peak (P &lt; 0.03) in yoga group; no change in controls</td>
<td>Improvement of 25.7% in quality of life scores (P &lt; 0.005) in yoga group</td>
</tr>
<tr>
<td>Tracy and Hart (2012)</td>
<td>Sedentary healthy non-yoga practitioners (n = 21)</td>
<td>6-Week RCT of multiple practices</td>
<td>Bikram yoga—26 series of postures in heated (35°C to 40°C) humidified studio (n = 10); Waitlist control (n = 11)</td>
<td>Pre-intervention VO2peak versus post-yoga intervention VO2peak</td>
<td>No change in VO2peak after yoga training; 23.8% increase in sit and reach score (P &lt; 0.001) and shoulder flexibility (P &lt; 0.05) with yoga</td>
<td></td>
</tr>
<tr>
<td>Chaya et al (2006)</td>
<td>Non-yoga (NY) and regular yoga practitioners (YFP) with &gt;6 months experience (n = 104)</td>
<td>Multiple practices on a single occasion</td>
<td>YFP—regular integrated yoga practice (n = 53); NY (n = 49)</td>
<td>Yoga practitioners versus non-yoga practitioners at rest (basal state)</td>
<td>Basal OC—9.3% less in female YFPs and 10.7% less in male YFPs (P &lt; 0.001) compared to NYs; Basal CO2—12.7% less in female YFPs and 14.3% less in male YFPs (P &lt; 0.05) compared to NYs; BMR—15.1% less (P &lt; 0.001) in YFP compared to NY and 13% less than the predicted by WYHOFAC/UNU</td>
<td>14.3% less (P &lt; 0.001) in male YFPs compared to NYs</td>
</tr>
<tr>
<td>Chaya and Nageshree (2008)</td>
<td>Non-yoga (NY) and regular yoga practitioners (YFP) with &gt;6 months experience (n = 88)</td>
<td>Multiple practices on a single occasion</td>
<td>YFP—regular integrated yoga practice (n = 51); NY (n = 37)</td>
<td>Yoga practitioners versus non-yoga practitioners at rest at 6 h in (basal) and 9 h (pre-sleep)</td>
<td>Basal OC—22% less (P &lt; 0.001) in female YFPs and 10.7% less (P &lt; 0.05) in male YFPs compared to NY females and males, respectively; Basal CO2—13.3% less in female YFPs and 14.8% less in male YFPs (P &lt; 0.05) compared to NY females and males; Basal O2—15.3% less in female YFPs (nonsignificant) compared to NY females; and males; Basal CO2—13.3% less in female YFPs and 14.8% less in male YFPs (P &lt; 0.05) compared to NY females and males; Basal CO2—13.3% less in female YFPs and 14.8% less in male YFPs (P &lt; 0.05) compared to NYs</td>
<td>23.3% less (P &lt; 0.005) in female YFPs and 15.6% less (P &lt; 0.05) in male YFPs during morning compared to NYs</td>
</tr>
</tbody>
</table>

Abbreviations: OC, oxygen consumption; HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; BMI, body mass index; NRCT, nonrandomized controlled trial; RCT, randomized controlled trial; FEV1, forced expiratory volume in 1 second; HRV, heart rate variability; CO2, carbon dioxide exhalation; BMR, basal metabolic rate; BR, breath rate.
Oxygen Consumption Changes with Yoga Practices: A Systematic Review

Chapter 6

of 12 postures) and report that oxygen consumption increased 20.5% above resting levels, 25% and 81% above the levels during static postures.

The reported increases in oxygen consumption seen with yoga practices are less than observed with maximal or submaximal exercise. Oxygen consumption during Thai yoga is reported to be 35.5% of VO2max,

Vinyasa yoga, 50%,

bow posture, 26.5%, and Shavasana (supine pose), 9.9%, of VO2max. Similarly, Iyengar, Ashtanga, and Hatha yoga sequences have been shown to be of lower intensity than submaximal exercise, having oxygen consumption that is 26%, 33%, and 54% lower than oxygen consumption during treadmill walking at 4 mph,

3 mph, or 2.5 mph, respectively.

While oxygen consumption is reported to increase during a yoga session, there are reports that oxygen consumption may fall below preession levels immediately after certain practices. During cyclic meditation, which involves a series of postural sequences interspersed with periods of relaxation, oxygen consumption is reported to increase by up to 55% during the active phase and then fall to 19% below preession levels in the immediate postsession period.

Similar results are reported in a further study, which reports a 32% decrease in oxygen consumption immediately after cyclic meditation.

Regular Yoga Practice, Physical Activity, and Oxygen Consumption

Table 4 presents 16 studies involving 516 participants that measured oxygen consumption at rest or during physical activity (submaximal and maximal) after 1 month to 24 months of integrated yoga practice (including asana, pranayama, and relaxation) along with 2 studies comparing oxygen consumption at rest in yoga and non-yoga practitioners and 1 study comparing oxygen consumption between groups who regularly practiced lotus posture and groups of regular exercisers or healthy sedentary subjects.

Most of these studies report that regular yoga practice leads to progressive reductions in oxygen consumption over time. In a 3-month cohort study, yoga practice was found to reduce oxygen consumption during submaximal exercise by 36% compared to baseline levels. A randomized trial involving male soldiers found that 6 months of yoga practice (n = 15) reduced oxygen consumption during submaximal exercise by 5.7% (P < .05) compared to no change in a physical training group (n = 15), while a nonrandomized study reports that 12 months of regular yoga practice with regular sports activity improved submaximal work efficiency in athletes with 51% greater work output per liter of oxygen consumed, compared to no change in regular sports activity group.

VO2max was also reported to increase with regular yoga practice, ranging from 6 weeks to 6 months in diverse populations. A 3% increase in VO2max is reported in the cohort of middle-aged yoga practitioners who practiced intensive yoga for 11 weeks and 7% increase in VO2max in a cohort of yoga navies who practiced integrated yoga for 8 weeks. Similarly, up to 7% increase of VO2max is reported in a randomized trial of 6 months in male soldiers with integrated yoga (n = 17) compared to no change in a physical training group (n = 11), and a 13% (P < .01) increase in VO2max is reported in elderly subjects in a randomized trial after 6 weeks of yoga with practice (n = 20), similar to significant increase with aerobic training (n = 20).

Increases in VO2max of approximately 17% are also reported after yoga practice in 2 cohort studies including a 6-week study of healthy subjects (n = 17) and an 11-week study of elderly yoga practitioners (n = 9). Similar increases in oxygen consumption are reported in an 8-week randomized controlled trial of patients with congestive heart failure who practiced yoga (n = 9), compared to no change in a standard medical therapy group (n = 10). A further cohort study of female physical trainers found that 1 month of yoga practice led to 14% greater maximal work efficiency. Maximal work efficiency was also seen to improve in a nonrandomized controlled trial by 34% in athletes after 24 months of regular yoga practice compared to a control group practicing physical exercise.

Not all the studies report improvement in oxygen consumption or work efficiency with regular yoga practice. A 12-month randomized study reports no change in oxygen consumption during submaximal exercise in either a yoga or aerobic training group. In another randomized study, no change in VO2max is reported after 8 weeks in a yoga practice group (n = 10) compared to a no-intervention control group (n = 11). Similarly, two 3-month cohort studies report no change in oxygen consumption at rest after regular yoga practice. and similar results are reported in a 12-month randomized controlled trial.

When examining oxygen consumption at rest, 2 studies report basal oxygen consumption to be significantly less in regular yoga practitioners compared to non-yoga practitioners. One study reports that regular yoga practitioners had basal metabolic rate 1% less than predicted based on the FAO/WHO/UNU equation and that oxygen consumption during basal conditions was significantly less in regular yoga practitioners compared to non-yoga practitioners. Similar results were reported in the second study, which report that regular yoga practitioners had basal metabolic rate that was 17.8% less than non-yoga practitioners.

Discussion

Studies published to date suggest that yoga practices can have profound metabolic effects producing both significant increases and decreases in oxygen consumption. Like other physical activity, physical yoga postures can increase oxygen consumption dramatically, yet yoga practices do not involve maximal exertion. For example, dynamic postures such as cobra pose are reported to increase oxygen consumption by 383% or around 1220 mL/min, which is less than half that produced with maximal exertion in the average untrained healthy male. The most
dramatic change seen with yoga is reduction of oxygen consumption, with reports of yoga practices downregulating the sympathetic nervous system and producing modest reductions in oxygen consumption comparable to practices such as progressive muscle relaxation, closed eyes relaxation, and listening to music,\textsuperscript{123,124,134,136} as well as reports of dramatic reductions up to 40%.\textsuperscript{90} This suggests that yoga may downregulate the hypothalamic–pituitary–adrenal axis and the sympathetic activity and therefore promote relaxation and stress relief.

Regular yoga practice also appears to have a training effect, with regular yoga practitioners consistently showing significant reductions in oxygen consumption during normal physical activity compared to non-yoga practitioners. Thus, unlike other physical training, which generally increases resting metabolic rate, regular yoga practice is reported to decrease resting oxygen consumption to levels lower than predicted by the FAO/WHO/UNU equation.\textsuperscript{70} This may be due to regular physical training producing an increase of muscle mass, which requires greater oxygen consumption supply at rest, whereas yoga training may instead increase efficiency of mitochondrial oxidative phosphorylation and reduce oxygen demand.

Yoga practices are also reported to shift lactate threshold (anaerobic threshold) and improve work efficiency, indicating aerobic capacity and reduced muscle fatigue to a greater degree compared to physical activity.\textsuperscript{112} These results are supported by a randomized crossover trial documenting reduced blood lactate, heart rate, and blood pressure with regular yoga practice.\textsuperscript{106}

A recent review of yoga and exercise found that yoga may be as effective as or better than aerobic exercise at improving a variety of health-related outcome measures in both healthy and diseased populations.\textsuperscript{147} Despite multiple studies demonstrating the benefits of yoga in various clinical conditions, only one small study examined the effects of yoga and oxygen consumption in a clinical population. This study reported increased aerobic capacity (VO$_{2\max}$) in patients with congestive heart failure after practicing yoga postures, breathing techniques, and meditation over a period of 8 weeks.\textsuperscript{30} Previous research also suggests that instruction on respiration and relaxation, in addition to physical exercise, enhances respiratory sinus arrhythmia and slows heart rate and breath rate in myocardial infarction patients during rehabilitation\textsuperscript{148} and that slow respiratory respiration can be used as a therapeutic tool for anxiety,\textsuperscript{149} hypertension,\textsuperscript{150,151} and asthma.\textsuperscript{152} Due to the wide variety of yoga practices and styles, further research is required to determine the most appropriate practices for different clinical conditions. Typical yoga sessions of different styles appear to differ in exercise stimulus, resulting in varied increase in oxygen consumption\textsuperscript{125,126,134,137} with profound increases reported during dynamic posture sequences compared to static posture sequences.\textsuperscript{126,134} Different yoga practices and styles, however, are likely to have different health and fitness benefits.\textsuperscript{153,154}

It appears that breathing rate and retention periods are critical in determining oxygen consumption and that yoga practitioners are able to vary their breathing rate widely with reported breath rates ranging from 1 breath/min to more than 230 breath/min. Oxygen consumption is also reported to paradoxically increase by up to 10% despite breath rates of only 1 breath/min. The most profound changes in oxygen consumption with breathing techniques are seen in advanced yoga practitioners who are reported to increase their oxygen consumption by 208% and their carbon dioxide exhalation by 395% when performing Bhastrika breathing at 232 breaths/min, or decrease their oxygen consumption by 15% when performing the same type of breathing at 12 breaths/min. Similarly, altering the retention period during Ujjayi breathing is reported to either increase oxygen consumption by up to 52% when performed with a short retention period with an inspiration–retention–expiration ratio of 1:1:1 or decrease by 19% when the same type of breathing is performed with a longer retention period of inspiration–retention–expiration ratio of 1:4:4. Ultradimensional rhythms in nasal cycles and unilateral nostril breathing practices may also influence oxygen consumption with alternate nostril breathing being reported to increase oxygen consumption by up to 150%.\textsuperscript{134} Advanced yoga practitioners appear to be able to exert extraordinary conscious manipulation of their metabolic and autonomic functions,\textsuperscript{155,156} with reports of yogis being able to tolerate ambient carbon dioxide levels of more than 7% and oxygen levels less than 12%.\textsuperscript{156} There are further reports of advanced yogis being able to reduce oxygen consumption by 40% while meditating in an airtight pod\textsuperscript{157} and survive 8 days in an airtight pod with an unrecordable electrocardiogram.\textsuperscript{157} These reports appear inexplicable, yet are similar to reports of advanced Zen meditators being able to decrease oxygen consumption up to 20% and dramatically reduce their respiratory rate to 1.5 to 2 breaths/min during Zazen meditation. True-no meditators being able to increase or decrease their oxygen consumption by more than 60% during seated meditation,\textsuperscript{158} and reports of modern free divers being able to hold their breath for more than 10 minutes while diving to depths of more than 200 m.\textsuperscript{159} So far, these extreme feats of metabolic control are poorly documented and limited to single case studies or small cohorts. They therefore require further investigation and documentation as they may provide clues about extending the limits of human endurance and metabolic control.

This review suggests that yoga can have profound metabolic effects with a consistent picture emerging from experimental, cohort, nonrandomized, and randomized controlled trial studies. Yet most of these studies are of poor methodological quality and do not provide adequate reporting of the study design, study population, yoga practices, methods of measurement, or statistical methods. Furthermore, most studies were performed in India ($n=35$) and included only small numbers of adult male yoga practitioners without matched comparison groups. Furthermore, there are 2 randomized controlled trials of healthy people that report no change in oxygen consumption with yoga despite significant changes in other physiological measures. Of these, a controlled trial ($n=16$) reported significant improvements in flexibility with yoga but no change in maximal aerobic capacity,\textsuperscript{159} while another controlled trial ($n=18$) reported improvements in respiratory variables and
breath hold time but no change in oxygen consumption during submaximal exercise with yoga. A further cohort study (n = 10) reported significant improvements in biochemical and anthropometric parameters after 3 months of yoga practice but did not find any change in oxygen consumption.

The small sample sizes, variable practices, and limited, nonclinical populations involved in the reviewed studies make it difficult to generalize to wider populations or make definitive statements about specific practices. Thus, more rigorous studies with larger samples and standardized practices are required to determine the role of yoga in modulating oxygen consumption and determine if the reported results can be reproduced in non-Indian, female, adolescent, and non-yoga-practicing populations as well as in different clinical conditions. The reports of advanced yogis performing extraordinary feats also warrant further investigation using modern equipment and research methodologies.

Conclusion
Research to date on yoga and metabolism includes many heterogeneous yoga practices in studies of poor methodological quality. This research suggests that yoga practices can produce dramatic changes in oxygen consumption and metabolism and that regular yoga practice may lead to reduced resting metabolic rate. Research further suggests that different yoga postures and breathing practices, which involve the control of respiratory rate and retention periods, may produce markedly different metabolic effects with reductions in oxygen consumption being more dramatic than increases. The volitional control over autonomic functions and increased metabolic endurance demonstrated by advanced yoga practitioners warrant further investigation. Rigorous research on standardized practice is required to determine the relevance of yoga practices in various clinical conditions.

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Chapter 7
Yoga and Heart Rate Variability (HRV): A Systematic Review

Introduction

Heart Rate Variability (HRV) arise from the dynamic interplay of the sympathetic and parasympathetic nervous system and their associate physiological, emotional and cognitive influences. While many study suggest that yoga influence HRV, yet such studies have not been systematically review. This review with 49-studies suggests that yoga has profound effect on cardiac autonomic regulation with increased HRV and vagal dominance.
Heart rate variability (HRV) arises from the dynamic interplay of the sympathetic and parasympathetic nervous systems and their associated physiological, emotional and cognitive influences. HRV has been used as a proxy for health and fitness and as a sensitive and accessible indicator of autonomic regulation and therefore appears well placed to assess the changes occurring with mind-body practices that facilitate autonomic balance. While many studies suggest yoga influence HRV, yet such studies have not been systematically reviewed. The reviewed studies \((n=49)\) including 11 randomised controlled trials categorised according to type of interventions. The review suggest profound effects of yoga on cardiac autonomic regulation with increased HRV and vagal dominance during yoga practices and increased vagal tone at rest in regular yoga practitioners compared to non-yoga practitioners. Yoga facilitates resonance between respiration, muscle contractions, HR and baroreflexes that enhance autonomic efficiency and lead to greater self-regulation. It is premature to draw any firm conclusions as the studies were of poor quality, small sample size, with insufficient reporting of study design and statistical methods. To determine the autonomic and clinical effects of yoga, the future studies must have rigorous design and include detailed reporting of practices along with corresponding change in respiration.

**Keywords:** yoga, pranayama, yogic, vagal tone, Respiratory Sinus Arrhythmia (RSA), autonomic

### 7.2 Heart Rate Variability: A Measure of Cardiac Autonomic Control

The Heart Rate (HR) in healthy human is not steady as it is influenced by physical, emotional and cognitive activities (Thayer et al. 2009) and physiological oscillations that to lead to variable beat-to-beat fluctuations in heart rate known as Heart Rate Variability (HRV). HR and HRV are perhaps the most sensitive and easily accessible indicators of autonomic regulation and vagal activity. A high resting heart rate is a known risk factor for cardiac disease (Habib 1999; Kelley...
2005), while a lower resting HR reflects efficient vagal activity and flexible autonomic regulation. HRV reflects the dynamic balance arising from the co-activation, co-inhibition or reciprocal activation or inhibition of the sympathetic and parasympathetic nervous systems (Berntson et al. 1997) and therefore HRV also provides a proxy for the health, adaptability, flexibility and neural regulation of the cardiovascular system (Acharya, R. U. 2007; Berntson et al. 1997; Task Force 1996).

There is growing evidence that physiological and psychological stress disrupts autonomic balance and that prolonged autonomic imbalance is associated with a wide range of somatic and mental diseases that are characterised by dominant sympathetic and inhibited parasympathetic activity (Thayer et al. 2012). Such autonomic imbalance is reflected in measures of HRV, which have been positively associated with aerobic fitness (Verlinde et al. 2001), resilience to stress (Oldehinkel, Verhulst & Ormel 2008), psychological and physiological flexibility (Souza et al. 2007) and negatively associated with cardiovascular disease (Thayer et al. 2012), stress (Jarczok et al. 2013; Porges 2011; Thayer et al. 2012) and negative affective states characterised by autonomic inflexibility and maladaptive stress responses (Reyes del Paso et al. 2013).

7.2.1 Quantification of HRV

HRV is generally measured using the R-R interval (QRS peak) on an electrocardiogram and a variety of measures have been used to operationalize HRV. The beat-to-beat fluctuation in instantaneous heart rate reflects the chaotic properties of the heart and provides a strong indicator of adaptability, and resilience. The R-R interval is generally measured in either the time or frequency domain. At rest with the time domain reflects respiratory sinus arrhythmia, which is mediated by parasympathetic cardio-vagal outflow (Acharya, R. U. 2007; Task Force 1996).

Frequency domain analysis (power spectrum/spectral power) involves decomposition of sequential R-R intervals into sinusoidal components of different amplitude and frequency (Acharya, R. U. 2007; Task Force 1996) that are suggested to reflect autonomic balance (Malliani 2005; Montano et al. 2009). To
quantify HRV as a reliable marker of autonomic cardiac control Pagani and colleagues have recommended the use of normalised units ‘n.u’ rather than power (ms²) (Berntson et al. 1997; Malliani 2005, 2006) and it is important that the spectral profile is measured under controlled resting conditions as HRV is sensitive to changes caused by controlled breathing or talking (Bernardi et al. 2000). Power spectrum analysis is most commonly performed using the ‘Fast Fourier Transformation’, which provides a simple and fair representation of all frequencies provided that at least 5 minutes of reliable data is recorded. This analysis allows the classification of HRV into three frequency bands; very low frequency (VLF), low frequency (LF) and high frequency (HF) (Acharya, R. U. 2007; Task Force 1996).

The total frequency or variance reflects the net effect of all physiological oscillations contributing to HRV while the High Frequency ‘HF’ band (0.15 – 0.4Hz) is associated with the frequency of spontaneous breathing (9-24 breaths/min). The HF band therefore provides an index of parasympathetic activity with HR oscillations in the HF band being an accepted index of vagal tone and RSA, which is inversely related to respiration rate and directly related to tidal volume under rest conditions (Berntson et al. 1997; Task Force 1996).

While the HF band is widely accepted as a measure of parasympathetic tone, interpretation of the LF band (0.04 – 0.15 Hz) is less clear and somewhat controversial (Eckberg 1997; Goldstein et al. 2011; Reyes del Paso et al. 2013). Higher values of LF and LF/HF adjusted for total power are widely used as an index of sympathetic tone and poor autonomic regulation, yet this may lead to incorrect conclusions because if the frequency of respiration is slowed and approaches the LF range (3 -9 BPM) entrainment occurs so that the LF band reflects resonance between oscillations in HR, RR and BP rather than sympathetic tone. (Berntson et al. 2008; M. 2007; Montano et al. 2009). While such entrainment may lead to improved BP control and gas exchange via efficient ventilation/perfusion matching (Lehrer, PM, Woolfolk & Sime 2007) it obscures the interpretation of LF or LF/HF as measures of sympathetic tone or autonomic balance.
Interpretation of the very low frequency ‘VLF’ band (<0.04) Hz is even less clear than that of the LF band. While it is accepted that the VLF band is related to thermoregulation and is sympathetically mediated (Berntson et al. 1997), standardised guidelines on HRV measurement suggest that VLF band measures cannot be accurately assessed from short-term recordings, and thus the VLF band is not often reported in HRV studies (Berntson et al. 1997; Task Force 1996).

7.3 Mind-Body Interventions, Autonomic Control and HRV

Facilitating mind-body interaction has been a feature of many different cultural and spiritual practices that are used to promote and sustain health and facilitate wellbeing and spiritual awakening. Mind-body interventions such as meditation focus on balancing the bidirectional communication between the brain and the peripheral organs (Astin et al. 2003) and often focus on eliciting relaxation. Such relaxation responses can be elicited voluntarily, yet are regulated via autonomic activity characterised by enhanced vagal activity (Taylor, AG et al. 2010) and parasympathetic dominance (Benson, Greenwood & Klemchuk 1975) leading to reduced oxygen consumption, blood pressure, HR and respiratory rate (Beary & Benson 1974; Wallace, Benson & Wilson 1971) along with decreased sympathetic activation (Benson, Greenwood & Klemchuk 1975).

Several studies that have examined HRV during mind-body interventions report varied outcomes, which may arise due to differences in breathing frequency and amplitude. In two different studies, Zen meditators demonstrated high oscillatory peaks in the LF band during meditative periods associated with slow breathing (3-9 breaths/min) (Cysarz & Büssing 2005; Lehrer, P, Sasaki & Saito 1999), while other studies report augmented HRV with decrease in LF/HF ratio or increased HF-HRV during periods of Zen meditation (Takahashi et al. 2005; Wu, SD & Lo 2008), Qigong meditation (Lee et al. 2002) and Vipasana meditation (Krygier et al. 2013; Telles & Mohapatra 2005).

7.4 Yoga and Autonomic Influence

Yoga involves a diverse range of mind-body practices such as meditation/relaxation techniques (dhayana), breathing practices (pranayama) and
physical postures (asana) that aim to integrate the mind and body and bestowing the practitioner with physical, mental, intellectual and spiritual development. Two systematic reviews report that yoga practices have profound effects on autonomic and metabolic activities (Innes, Bourguignon & Taylor 2005; Tyagi & Cohen 2013) and improve cardiovascular functions (Innes, Bourguignon & Taylor 2005). Several studies further report associations between yoga and markers of autonomic activity such as heart rate (Innes, Bourguignon & Taylor 2005), baroreflex sensitivity (Bowman, Clayton & Murray 1997), galvanic skin resistance (TellesRaghavendra, et al. 2013), evoked potentials (Telles, Singh & Puthige 2013), attention (Telles et al. 2008), cognitive ability and emotional regulation (Chaya, MS et al. 2012) and mental resilience (Cramer, H. et al. 2013). Further studies report that regular yoga practice improves a wide range of clinical conditions associated with autonomic dysfunction, such as; hypertension (Hagins et al. 2013), diabetes (Aljasir, Bryson & Al-Shehri 2010), anxiety (Li & Goldsmith 2012), depression (Pilkington et al. 2005) and pain (McCall et al. 2013). A further comprehensive review of yoga studies and cardiovascular risk suggests that yoga enhances autonomic balance and reduces sympathetic activation and cardiovascular risk (Innes, Bourguignon & Taylor 2005).

Despite the known relationship between autonomic function and HRV, and multiple studies reporting changes in HRV with yoga practice, the literature on yoga and HRV has not yet been subject to any specific review. This current paper aims to review the existing literature and document the long and short term effects of different yoga practices on HRV.

### 7.5 Methodology

For this systematic review, a comprehensive search of multiple databases, including Scopus, PUBMED, PSYCHINFO, CINHAL, Cochrane and Science Direct Database was conducted, and a separate search was performed in Indian medical journal through IndMed which indexes more than 100 prominent Indian scientific journals. The primary search terms included Yoga, yogic, pranayama, yoga nidra, breathing, relaxation and meditation, Transcendental Meditation, Brahmakumari
meditation, *AUM* meditation, *mantra* meditation, *Kundalini* meditation, *Kriya* Yoga, *Ananda* Yoga, *Sudershan Kriya* with key words heart rate variability, respiratory sinus arrhythmia, autonomic, sympathetic, parasympathetic and vagal. The bibliographies of identified papers were also searched for relevant articles. All studies that reported a measure of HRV associated with any yoga practice including yoga asanas (postures), pranayama (breathing), meditation and yogic relaxation/nidra practices used either alone or as an integrated practice were included. Studies that included meditative practices directly associated with yoga such as Transcendental Meditation were also included in the review.

Studies were excluded if they were not in English, unobtainable or only involved meditation and relaxation practices that are not directly associated with yoga such as Zazen/Zen Buddhist meditation, Vipassana Meditation, concentrative meditation, gTummo yoga, Qigong, Relaxation Response (RR), Progressive Muscle Relaxation (PMR) and Autogenic Relaxation (AR). The search was performed for articles published up to Dec 2013 and was not otherwise restricted by date or study population.

Selected studies were categorized according to the type of intervention – relaxation/meditation, breathing, postures/integrated yoga and the quality of the randomised controlled trials ‘RCT’ was assessed using a Jadad score (Jadad & Enkin 2008)

### 7.6 Results

This review included 49 studies involving 1698 experimental subjects with study durations ranging from a single session to six months. A total of 11 RCTs were located with all of them having a Jadad score of 3 or less. A flow chart of the study search including the numbers of papers identified is shown in Figure 7.6. Studies, categorised according to the type of intervention (relaxation/meditation, pranayama practice, integrated yoga/asana practice) are presented in Tables 7.6.1- 7.6.3(b).
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7.6.1 HRV and Yogic Relaxation or Meditation

Table 7.6.1 summarises the 10 studies investigating HRV with yoga relaxation and/or meditation. Six of these studies are laboratory-based studies involving regular yoga/meditation practitioners, while four studies are ranging from 6 weeks to over 6 months. These studies, which include 521 participants, reported varied outcomes with 6 studies reporting increases in HRV during yoga relaxation and/or meditation and 4 studies reporting no change.

Five studies compared HRV at baseline with HRV during or after a single laboratory session of yoga relaxation or meditation practice in regular yoga practitioners while a further study compared HRV during different stages of meditation. Of these studies, three reported reduced LFn.u and increased HFn.u
(Markil et al. 2012; TellesRaghavendra, et al. 2013; Vempati, R & Telles 2002), while two different studies that investigated Transcendental Meditation in advanced meditators and reported increased HF amplitude (ms²) during periods of meditation compared to baseline eyes closed (Travis & Wallace 1999) and during period of transcending experience compared to other experiences during meditation (Travis 2001). The one study examining HRV during meditation (dhayana), focused thinking (dharana), non-meditative thinking (ekagrata) and random thinking (cancatla), reported reduced LFn.u and increase HFn.u during meditation (dhayana) and an increased LFn.u and reduced HFn.u during non-meditative thinking and random thinking (TellesRaghavendra, et al. 2013). Furthermore, one study that compared HRV at baseline with HRV after yoga relaxation reported no change in HRV (Vempati, R & Telles 1999).

Of the three randomised studies, one study of coronary heart disease patients (with Jadad score 3) reported a marginal increase in HF-HRV ms² (p<.07) after 16 weeks of Transcendental Meditation compared to a control group that received heath education (Paul-Labrador et al. 2006). Of the two randomised controlled trials reporting no change in HRV, one (with Jadad score 3) reported no change after 10 weeks of Transcendental Meditation (Travis et al. 2009) while another (with Jadad score 2) reported no change in HRV with 6 months of yoga relaxation practice (Monika et al. 2012). Additionally, a non-randomised controlled trial of adolescents reported no change in HRV after 6-weeks of yoga relaxation practice (Madanmohan 2004).

7.6.2 HRV and Yoga Breathing

Table 7.6.2 (a) summarises 5 studies that involved rapid breathing practices. The two studies that measured HRV during rapid Kapalbhati breathing reported decreases in LFn.u and HFn.u (Peng et al. 2004; Stancak et al. 1991), while the two studies that compared HRV before and after Kapalbhati breathing reported increased LFn.u. and reduced HFn.u. (Raghuraj et al. 1998), or no change in LFn.u and HFn.u but a reduction in proportion of NN50 (pNN50) after the practice (Telles, Singh & Balkrishna 2011). The only longitudinal study was an RCT (with Jada Score 2) of elderly people regularly performing Bahstrika (rapid shallow breathing) that compared HRV before and after a 4-month intervention period.
This study, which measured HRV during a period of regulated breathing at 12 BPM reported decreases in LFn.u. and LF/HF in the breathing group compared to controls (Santaella et al. 2011).

Table 7.6.2 (b) summarises the 11 studies that involved slow breathing practices, nine of these studies were laboratory based, while one was a longitudinal cohort study involving non-yoga practitioners and one a non-randomised controlled trial with chronic obstructive pulmonary diseases (COPD) patients. Eight of these studies either regulated breathing at a breath rate between 1-9 BPM, or allowed spontaneous breathing with a rate below 9 BPM.

Eight laboratory based studies compared HRV before, and either during or after various slow breathing practices. Of these two studies report increases in LFms² (Ghiya & Lee 2012; Peng et al. 2004) and two report increases in LFn.u. with increase in LF/HF observed during breathing practice (Ghiya & Lee 2012; Peng et al. 2004; Raghuraj & Telles 2008; Raghvendra 2013) while one study report increased HR oscillations in LF band (Peng et al. 1999). Similar increased HR oscillation in LF Band significant decrease in respiratory frequency was also reported during mantra chanting and rosary prayer compared to post-session spontaneous breathing (BernardiSleight, et al. 2001). The one study that examined extremely slow breathing at 1 BPM in a single practitioner, reported an increase in VLFms² and LF/HF and corresponding increases in HR while also reporting reductions in LFms² and HFms² (Jovanov 2005). A further study that compared HRV in yoga practitioners and non-practitioners during deep slow breathing at 6 BPM reported higher Standard deviation of NN intervals '(SDNN), root mean square of successive differences (RMSSD) and the number of pairs of successive NNs that differ by more than 50ms (NN50) in yoga practitioners during the practice (Muralikrishnan et al. 2012).

Two studies examined combinations of breathing that include both fast and slow breathing practices. These studies report increased LFms² and reduced RMSSD during the practices (Selvaraj et al. 2008) and decreased sympatho-vagal balance with increased HFn.u and reduced LFn.u. outflow to the heart after 2 months of regular practise (Bhimani et al. 2011). A further 3 months study
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7.6.3 HRV and Yoga Postures and Integrated Yoga

Table 7.6.3 (a) summarises 21 studies that investigated either yoga postures or integrated yoga practices that combine postures breathing and meditation. The majority of these studies report enhanced autonomic balance with yoga practices. Of the 3 RCTs (only one with Jadad score of 3) one RCT with 24 participants (Patil et al. 2013) and two RCT’s, each with more than 60 female participants (Huang, FJ, Chien & Chung 2013; Satyapriya et al. 2009), report increased HFn.u. and decreased LFn.u. and LF/HF ratio with regular integrated yoga practise. A decrease in LFms³ was also reported in a 8 week longitudinal cohort study of depressive patients practicing Iyenger yoga (Shapiro et al. 2007) and an increase in pNN50 was reported after 8 weeks practicing inverted or semi inverted yoga postures (Papp et al. 2013).

Of the reviewed laboratory studies, four involved cyclic meditation, which involves a series of postures interspersed with relaxation practices. Three of these studies report increased HFn.u and decreased LFn.u along with decreased LH/HF ratio post intervention compared to baseline (An et al. 2010; Sarang & Telles 2006; Vempati, RR, Telles, S. 2000), while one reported higher sympathovagal balance and lower LFn.u during sleep after the practice of cyclic medication compared to rest (Patra & Telles 2010). Further laboratory studies reported a decreased LH/HF ratio with yoga inversion postures (Howorka et al. 1995) and increased time domain indicators of vagal activities with Iyenger yoga (Khattab et al. 2007), laughter yoga (Dolgoff-Kaspar et al. 2012), chair-based yoga practise (Melville et al. 2012) and integrated yoga (Shankarappa & Prabha 2013).

In contrast to these results, one study reported increased LF/HF ratio indicating decreased autonomic balance after performing yoga headstands (Manjunath & Telles 2003) and six studies, reported no change in HRV with various other yoga practices. This includes four RCTs of integrated practices (only one of which had Jadad scores of 3) involving less than 40 subjects (Bidwell et al. 2012; Bowman, Clayton & Murray 1997; Cheema et al. 2013; Telles et al. 2010),
one non-RCT with hypertensive patients (Niranjan et al. 2009), and a small cohort study of 11 hypertensive patients and 6 diabetic patients practicing integrated yoga for 7 days (Singh & Telles 2009).

Table 7.6.3 (b) summarises four studies comparing HRV in the resting state in non-yoga practitioners and regular yoga practitioners. Three of these studies report enhanced parasympathetic activity measured in time and/or frequency domain in regular yoga practitioners (Friis & Sollers Iii 2013; Muralikrishnan et al. 2012; Satin, Linden & Millman 2013) compared to non-yoga practitioners, while one study reported lower parasympathetic activity in regular practitioners compared to non-practitioners (Chaya, MS et al. 2008).

7.7 Discussion

This review of studies that measured HRV during or after yoga suggest that yoga can have profound effects on cardiac autonomic regulation, however the reviewed studies are of poor quality with few studies providing robust statistical analysis or estimation of effect sizes. Furthermore, as in many other studies of HRV (Acharya, R. U. 2007), few studies on yoga and HRV provide details of respiratory rate making it extremely difficult to distinguish changes in HRV due to changes in autonomic cardiac control and changes in HRV due to alterations in respiration. This is compounded by the differences in yoga practices and procedures used in various studies as many yoga practices involve alteration of respiration and subtle differences among studies, including instructions to subjects, the type of training given, and the exact respiration rates, may lead to large differences in HRV measures.

Experimental and cohort studies report vagal dominance in both the time and frequency domain, during and after various yoga practices including meditation, relaxation, breathing and integrated practices. The reviewed studies further report that regular yoga practice increases vagal tone in yoga practitioners compared to non-yoga practitioners (Friis & Sollers Iii 2013; Muralikrishnan et al. 2012), sedentary individuals (Satin, Linden & Millman 2013) and individuals who regularly practice aerobic exercise (Friis & Sollers Iii 2013). The reviewed studies report that yoga practices can directly enhance vagal and inhibit sympathetic
activity and while different studies examine different yoga styles and practices, a common element of these practices appears to be a focus on mindfulness, relaxation and restorative activities that enhance vagal dominance.

Although the mechanism by which yoga influences autonomic activity is not well understood, some yoga practices appear to directly stimulate the vagus nerve and enhance parasympathetic output (Innes, Bourguignon & Taylor 2005) leading to parasympathetic dominance and enhanced cardiac function, mood and energy states, as well as enhanced neuroendocrine, metabolic, cognitive and immune responses (Innes, Bourguignon & Taylor 2005). While the bidirectional flow of the vagus nerve allows adaptive and flexible interaction between the amygdala, prefrontal cortex and the peripheral organs, an extensive body of literature further suggests that this interaction not only mediates autonomic responses but also cognitive behavioural and emotional responses (Thayer et al. 2012). As both the input and output of the central nervous system are directly linked to HRV (Thayer et al. 2012), HRV appears well placed to reflect the emotional and cognitive influences on organ function and the mind-body integration that occurs with many yoga practices.

The present review suggests that yoga breathing practices, which involve a variety of breathing patterns at frequencies ranging from less than 1 to greater than 120 BPM, can have profound effects on HRV and RSA, both of which are highly sensitive to breath-rate. Studies of high frequency Kapalabhati breathing at either 120 BPM or 60 BPM are reported to decrease vagal activity measured in either the frequency and/or time domain, with reductions being maintained after the practice (Raghuraj et al. 1998; Telles, Singh & Balkrishna 2011). In contrast, slow yoga breathing practices are reported to increase HR fluctuations in the LF band (Ghiya & Lee 2012; Raghuraj & Telles 2008; Raghvendra 2013) and/or increase the LF/HF ratio (Peng et al. 2004; Raghuraj & Telles 2008; Raghvendra 2013; Selvaraj et al. 2008) with some studies reporting simultaneous increases in HR (Ghiya & Lee 2012; Raghuraj & Telles 2008). It is interesting to note that some yoga slow breathing practices are reported to increase HR (Ghiya & Lee 2012; Jovanov 2005; Peng et al. 2004; Raghuraj & Telles 2008), while yoga meditation practices which may be associated with slow breathing are reported to reduce HR (Madanmohan 2004; Markil et al. 2012; Monika et al. 2012;
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TellesRaghavendra, et al. 2013; Vempati, R & Telles 2002). This may be due to slow breathing being an active process that is associated with heightened attention and an increased metabolic rate, while meditation is a more passive practice that is associated with diminished attention and reduced metabolic rate (Tyagi & Cohen 2013).

High amplitude peaks in the LF range during rhythmical slow breathing between 4.5-6.5/min reflect resonance characteristics of the cardiovascular system where RSA interacts with the baroreflex, which is based on blood pressure and vascular tone as well as blood volume and viscosity (Berntson et al. 1997). Breathing at this resonant frequency, or other rhythmical stimulation at this frequency such as rhythmical skeletal muscle contraction (Lehrer, P et al. 2009; Vaschillo, EG et al. 2011), increases HRV and this is reflected in large increases in the LF band and simultaneous decreases in the HF band with corresponding increases in the LF/HF ratio, as well as increases in time domain measures of HRV and RSA. Such resonance effects are reported with yoga slow breathing practices (Peng et al. 1999) as well as with yoga mantra chanting (BernardiSleight, et al. 2001; Peng et al. 2004), and some meditative practices (Peng et al. 2004; Peng et al. 1999).

There is strong evidence that when the system is stimulated at this frequency a phase relationship occurs between HR and BP oscillations (at 180°) and between HR oscillations and respiration (at 0°) generating high amplitude HR peaks in the LF range that account for higher total HRV (Lehrer, PM, Vaschillo & Vaschillo 2000) as well as a decrease in HR (Wang, SZ et al. 2010). Thus, when people breathe at this rate, gas exchange is most efficient (Lehrer, PM, Woolfolk & Sime 2007) and leading to better oxygen saturation and enhanced tolerance to exercise and altitude. Regular practice of such breathing may also lead to changes in resting RSA and improved baroreceptor activity with positive autonomic effects, such as those observed with HRV-Biofeedback training (Vaschillo, E et al. 2002; Vaschillo, EG, Vaschillo & Lehrer 2006) and regular yoga practitioners (BernardiGabutti, et al. 2001; Spicuzza et al. 2000).

While slow breathing leads to resonance in the LF range, very slow breathing may lead to resonance in the VLF range and thus activation of sympathetically
mediated thermoregulatory mechanisms. This is suggested by one of the reviewed studies that reports feelings of warmth and reduced LF and increased ‘VLF’ (0.0003 – 0.04 Hz) power in an advanced yogi breathing at a frequency of around 1 BPM (Jovanov 2005). This is supported by another study of advanced Zen meditators who reported feelings of warmth while displaying increased oscillatory peaks in both the LF and VLF band accompanied with reductions in HR during meditation (Lehrer, P, Sasaki & Saito 1999).

It is interesting to note that advanced meditators appear to be able to voluntarily manipulate what are often considered involuntary autonomic functions such as peripheral temperature control. For example, one advanced yogi is reported to voluntarily produce a temperature difference of 11°F on different parts of the same palm (Green 1977). A further report suggests that advanced g-Tummo meditators are able to produce dramatic increases of up to 8.3°C in peripheral body temperature (finger and toes) (Benson 1982; Kozhevnikov et al. 2013) and dry wet bed-sheets placed over their shoulders in a 40°F room without shivering (Cromie 2002). While the physiological mechanisms behind such phenomena remain unexplained, previous studies have shown that yoga practices can have profound effects on oxygen consumption and metabolic rate (Tyagi & Cohen 2013) and it appears they may also involve cognitive control over autonomic functions such as vasodilation and vasoconstriction.

The ability of yoga to influence autonomic function has been the subject of numerous studies that suggest that yoga practices reduce autonomic arousal and assist with a wide range of stress-related disorders (Khalsa 2004). Yoga practices have also been reported to reduce anxiety and induce relaxation, with effects comparable to other stress-reducing techniques such as cognitive behavioural therapy and African dance (Chong et al. 2011). While at least some of the stress-relieving effects of yoga may be related to altered autonomic arousal, clinical improvements with yoga are not necessarily reflected by changes in HRV. For example, yoga practices are reported to reduce HR, without corresponding changes in HRV (Bowman, Clayton & Murray 1997; Monika et al. 2012) and improvements in high frontal coherence are reported with Transcendental Meditation (Travis et al. 2009) and improvements in quality of life (Bidwell et al. 2012), flexibility (Cheema et al. 2013) and mood (Telles et al. 2010) are reported
with various yoga practices despite no change in HRV. It may be that many of the positive effects of yoga on autonomic function are due to resonance effects produced by changes in respiration or by other mechanism such as rhythmical skeletal muscle tension occurring during various yoga postures that may lead to vagal dominance and enhanced baroreflex gain without corresponding changes in HRV (Lehrer, P et al. 2009; Vaschillo, EG et al. 2011)

While the finding of increased HRV and improved vagal tone with yoga are consistent across most studies, it is premature to draw firm conclusions about the influence of yoga on HRV. Not all studies report HRV changes with yoga and the quality of most studies published to date is poor with few studies providing adequate reporting of study design, study population, yoga practices, methods of measurements or statistical methods. Furthermore, the majority of studies to date have been performed in India with small numbers of adult yoga practitioners without matched comparison groups making it difficult to extrapolate results to other populations. Most studies also lack the standardised conditions required for accurate measurement of HRV and do not express HRV spectral components in normalised units as per international convention (Berntson et al. 1997; Montano et al. 2009; Task Force 1996). Further studies are needed that include more rigorous disclosure about the study methodology, the population involved and the yoga practices being performed before more definitive conclusions about the effects of yoga and HRV can be made.

7.8 Conclusions

Yoga practices, including meditation, relaxation, yoga postures, breathing and integrated practices appear to improve autonomic regulation and enhance vagal dominance as reflected by HRV measures, however it is difficult to make conclusive statements about yoga and HRV as existing studies are of poor quality and use a range of heterogenous measures. Changes in HRV with yoga may reflect resonance effects between respiration, muscle contractions, HR and baroreflexes that enhance autonomic efficiency and lead to greater mind-body balance and self-regulation. More rigorous studies are required to elucidate the autonomic and clinical benefits of such practices and it is vital that future studies
of yoga and HRV include detailed reporting of the yoga practices used and any corresponding changes in respiration.
Table 7.6.1: Heart Rate Variability with Yoga Relaxation and Meditation

<table>
<thead>
<tr>
<th>STUDY AUTHORS and YEAR</th>
<th>Population</th>
<th>Study design</th>
<th>Intervention</th>
<th>Length of intervention</th>
<th>Comparators</th>
<th>HRV (only statistically significant changes are reported)</th>
<th>Other outcomes</th>
<th>Jedad Scale Score for RCT</th>
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<tr>
<td>Vempati and Telles 2002 (Vempati, R &amp; Telles 2002)</td>
<td>Regular yoga practitioner (n=35)</td>
<td>Multiple practices in multiple session</td>
<td>Yoga beaded relaxation ; Supine rest</td>
<td>10 minutes each session</td>
<td>Baseline versus post intervention</td>
<td>Frequency domain: ↓ LFn.u.<em>, † HFn.u.</em>, † in LF/HF after yoga relaxation; No significant change after supine rest</td>
<td>↓ HR and ↓ skin conductance after relaxation; ↓ HR after supine rest</td>
<td>-</td>
</tr>
<tr>
<td>Markil et al. 2012 (Markil et al. 2012)</td>
<td>Regular Yoga practitioners with experience of &gt; 2 months; (n=20)</td>
<td>Multiple practices in multiple session</td>
<td>Hatha Yoga and relaxation (YR); yoga relaxation(R)</td>
<td>90 minutes each session</td>
<td>Baseline versus post intervention</td>
<td>Frequency domain: ↓ LFn.u., † HFn.u. after both session, Time Domain: ↑ in pNN50 after both session</td>
<td>↓ HR after both YR and R</td>
<td>-</td>
</tr>
<tr>
<td>Telles et al. 2013 (TellesRaghavendra, et al. 2013)</td>
<td>Regular male Yoga practitioners with &gt; 6 months experience (n=30)</td>
<td>Multiple practices in multiple session study</td>
<td>Meditative defocusing ‘dhyana’; meditative focusing ‘dharana’; non meditative thinking ‘ekagrata’; Random thinking ‘cancalta’</td>
<td>20 minutes each session</td>
<td>Baseline versus during intervention</td>
<td>Frequency domain: ↓ LFn.u., † HFn.u. during dhyana; † LFn.u., ↓ HFn.u. during ekagrata and cancalta interventions Time domain: ↑ NN50*, ↑pNN50 during dhyana</td>
<td>↓ in HR, BR* and ↓ in skin resistance and during dhyana</td>
<td>-</td>
</tr>
<tr>
<td>Travis and Wallace 1999 (Travis &amp; Wallace 1999)</td>
<td>Regular advanced meditators (n=20)</td>
<td>Single session</td>
<td>Transcendental meditation</td>
<td>10 minutes</td>
<td>Baseline eyes closed versus meditation</td>
<td>Frequency domain: † HF amplitude during meditation compared to baseline</td>
<td>↓ BR and skin conductance during meditation</td>
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<tr>
<td>Travis 2001</td>
<td>Single</td>
<td>Transcendental</td>
<td>15 minutes</td>
<td>Two different</td>
<td>Frequency domain:</td>
<td>Higher EEG</td>
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### Yoga and Heart Rate Variability (HRV): A Systematic Review

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<th>Intervention Details</th>
<th>Methodology</th>
<th>Summary of Findings</th>
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<tr>
<td>Travis (2001)</td>
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<td>↑ HF amplitude during transcending stage compared to other inner experience; No change in LF/HF</td>
</tr>
<tr>
<td>Vempati and Telles (1999)</td>
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<td>Yoga based relaxation; Supine rest</td>
<td>Baseline versus post intervention</td>
<td>Frequency domain: no change</td>
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<td>Madanmohan (2004)</td>
<td>RCT</td>
<td>Yoga relaxation group (n=26) no intervention control (n=17)</td>
<td>Pre intervention versus post intervention</td>
<td>Frequency domain: No change</td>
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<tr>
<td>Monika et al. (2012)</td>
<td>RCT</td>
<td>Yoga Nidra (n=75); No intervention control (n=75)</td>
<td>Pre intervention versus post intervention</td>
<td>Frequency domain: No change in either group</td>
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<tr>
<td>Travis et al. (2009)</td>
<td>Crossover RCT</td>
<td>TM: Immediate start meditation group (n=25); Waitlist control: delayed start meditation group (n=25)</td>
<td>Comparison between groups</td>
<td>Frequency domain: No significant different between group after first post session and second post session in HRV; High frontal coherence in the immediate start group after first post session</td>
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<td>Paul-Labrador et al. (2006)</td>
<td>Single blinded RCT</td>
<td>TM meditation group (52); Control-Health</td>
<td>Pre intervention versus post intervention and</td>
<td>Frequency domain: ↑ in HFms in meditation group from baseline; no significant change in control; No significant post intervention</td>
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</table>
Table 7.6.2 (a): Heart Rate Variability (HRV) and Yoga Rapid Breathing

<table>
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<th>Author</th>
<th>Population</th>
<th>Study Design</th>
<th>Intervention</th>
<th>Length of intervention</th>
<th>Comparators</th>
<th>Outcome HRV (only statistically significant changes are reported)</th>
<th>Other outcomes</th>
<th>Jedad Scale Score for RCT</th>
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<tr>
<td>Stancak et al., 1991 (Stancak et al. 1991)</td>
<td>Regular yoga practitioners (n= 17)</td>
<td>Single practice in single session</td>
<td>Kapalbhati at 120 breath/min</td>
<td>15 minutes (3 periods of 5 minutes each separated with 3 spontaneous breathing cycles)</td>
<td>Baseline versus during intervention</td>
<td>Frequency domain: ↓ VLFms(^2), ↓ LFms(^2), and ↓ HFms(^2); ↑ in HR(^\wedge), in SBP(^\gamma), and in DBP(^\gamma) during Kapalbhati; ↓ in BRS(^\alpha) during breathing;</td>
<td>↑ in HR(^\wedge) and in SBP(^\gamma)/DBP(^\gamma) during Kapalbhati; ↓ in BRS(^\alpha) during breathing;</td>
<td>-</td>
</tr>
<tr>
<td>Peng, Henry et al. 2004 (Peng et al. 2004)</td>
<td>Experienced Kundalini yoga meditators (n=11)</td>
<td>Multiple practices in single session each practice interspersed with 10 minutes of rest</td>
<td>Kapalbhati (rapid breath at 120 breath/min)</td>
<td>10 minutes</td>
<td>Baseline versus during intervention</td>
<td>Frequency domain: ↓ LFms(^2) (P&lt;.05), ↓ HFms(^2) (P&lt;.05), ↑ LF/HF (P&lt;.01),</td>
<td>↑ in HR;</td>
<td>-</td>
</tr>
<tr>
<td>Raghuraj et al. 1998 (Raghuraj et al. 1998)</td>
<td>Regular male yoga practitioners (n= 12)</td>
<td>Multiple practices in multiple session</td>
<td>Kapalbhati (120 breath/min): Alternate Nostril</td>
<td>1 minute Kapalbhati: 15 minutes ANB:</td>
<td>Baseline versus post intervention</td>
<td>Frequency domain: ↑ LF(n)u., ↓ HF(n)u., and ↑ LF/HF after Kapalbhati; No significant change after ANB</td>
<td>No change in HR with either breathing</td>
<td>-</td>
</tr>
</tbody>
</table>

Legends: LFn.u\(^1\) - Low frequency normalised unites; HFn.u\(^2\) - high frequency normalised units; HR\(^3\) - heart rate; pNN50\(^4\) - proportion of NN50; NN50\(^5\) - pair of successive NN's that differ by more than 50ms; BR\(^\alpha\) - breath rate; EEG\(^\alpha\) - electroencephalogram; NRCT\(^\beta\) - non-randomised controlled trial; RCT\(^\beta\) - randomised control trial; SBP\(^\gamma\) - systolic blood pressure; DBP\(^\gamma\) - diastolic blood pressure
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Table 7.6.2 (b): Heart Rate Variability (HRV) and Yoga Slow Breathing

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<th>Study Design</th>
<th>Intervention</th>
<th>Length of intervention</th>
<th>Comparators</th>
<th>Outcome HRV</th>
<th>Other outcomes</th>
<th>Jedad Scale Score for RCT</th>
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</thead>
<tbody>
<tr>
<td>Telles et al. 2011</td>
<td>Regular male yoga practitioners (n=38)</td>
<td>Multiple practices in multiple session</td>
<td>Kapabhati at 60 breath/min; breath awareness</td>
<td>15 minutes session (Three periods of 5 minutes each intermittent with 1 minute pause)</td>
<td>Baseline verse during and post</td>
<td>Frequency domain: No significant change with Kapabhati or breath awareness Time domain: Kapalbhati- ↓ pNN50 during and post intervention; Breath awareness - ↓ in pNN50 during and post intervention;</td>
<td>↓ in HR post Kapalbhati and breath awareness</td>
<td>-</td>
</tr>
<tr>
<td>Santaella et al. 2011</td>
<td>Elderly population &gt;60 years (n= 29)</td>
<td>RCT 4 months</td>
<td>Bhasrika breathing – a rapid shallow breathing (n=15); control -stretching (n=14)</td>
<td>4 months Pre intervention versus post intervention</td>
<td>Frequency domain: ↓ LFn.u., ↓LF/HF in breathing group, No significant change in controls</td>
<td>Improved respiratory variables (P&lt;.005) in breathing group</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Legends: VLFms⁴⁺ - very low frequency power; LFms²⁺ - low frequency power; HFms²⁻ - high frequency power; HR⁻ - heart rate; SBP⁻ - systolic blood pressure; DBP⁻ - diastolic blood pressure; BRS⁻ - baroreflex sensitivity;
<table>
<thead>
<tr>
<th>Year</th>
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<th>Changes in HR, SBP, and BR</th>
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<tbody>
<tr>
<td>1999</td>
<td>Chi meditators (n=8)</td>
<td>breathing and chanting; Chi Meditation group</td>
<td>during both meditation</td>
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<tr>
<td></td>
<td>Bernardi et al. 2001 (Bernardi et al. 2001)</td>
<td>Healthy Non yoga practitioners (n=23)</td>
<td>Frequency domain: ↑ LFms² (higher amplitude of HR oscillations in LF band) during mantra chanting and Ave Maria rosary (high peaks in LF band)</td>
<td>↑ in BRS and ↓ in BR² during both intervention</td>
</tr>
<tr>
<td></td>
<td>Peng et al. 2004 (Peng et al. 2004)</td>
<td>Experienced Kundalini yoga meditators (n=11)</td>
<td>Frequency domain: ↑ LFms² in slow breathing and mantra focusing; ↑ LF/HF during mantra focusing; ↑ in HR during segmented breathing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ghiya and Lee 2012 (Ghiya &amp; Lee 2012)</td>
<td>Non-yoga practitioners (n=20)</td>
<td>Frequency domain: ↑ TPms², ↑ LFms², ↑ HF ms² after ANB and paced breathing session</td>
<td>↑ HR after both the breathing session</td>
</tr>
<tr>
<td></td>
<td>Raghuraj and Telles 2008 (Raghuraj &amp; Telles 2008)</td>
<td>Regular male yoga practitioners (n=21)</td>
<td>Frequency domain: ANB- ↑ LnF.u., ↓ HF, ↑ LF/HF during breathing ranging to &lt; 10 breath/min; No significant change in frequency domain during RNB and LNB breathing</td>
<td>↑ HR and ↑ SBP α/DBP a during ANB; ↓ in BR during all breathing practices</td>
</tr>
<tr>
<td></td>
<td>Jovanov 2005 (Jovanov 2005)</td>
<td>Single male yoga practitioner (n=1)</td>
<td>Frequency domain: ↑ VL Fms², ↓ LFms², ↓ HFms², ↑ LF/HF</td>
<td>↑ HR during breathing</td>
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## Chapter 7
Yoga and Heart Rate Variability (HRV): A Systematic Review

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<tr>
<td>Raghavendra et al. 2013 (Raghavendra et al. 2013)</td>
<td>Regular Yoga practitioners (n= 50)</td>
<td>Multiple Practices in multiple session; Relaxation with breath regulation and breath regulation, 12 minutes per session</td>
<td>Baseline versus during intervention</td>
<td>Frequency domain: ↑ LFn.u., ↓ in HFn.u., and, ↑ LF/HF during relaxation with breath regulation; ↓ HR during relaxation with breath regulation;</td>
</tr>
<tr>
<td>Selvaraj et al. 2008 (Selvaraj et al. 2008)</td>
<td>Regular male yoga practitioners (n=8)</td>
<td>Single practice in single session; Shambhavi Mahamudra (incorporates sukha pranayama, aum chanting, rapid breathing and relaxed sitting)</td>
<td>15 minutes Baseline versus during intervention</td>
<td>Frequency domain: ↑ LF/HF Time domain: ↓ RMSSD², ↓ in pNN50⁶</td>
</tr>
<tr>
<td>Muralikrishnan et al. 2012 (Muralikrishnan et al. 2012)</td>
<td>Regular yoga practitioners (n=14); non-yoga practitioners (n=14)</td>
<td>Multiple practices in single session; Deep breathing at 6 breath/min</td>
<td>1 minute Comparison between group</td>
<td>Time domain: ↑ SDNN¹, ↑RMSSD, ↑NN5⁰ and ↑ pNN50 in yoga practitioners compared to non-yoga practitioners ↓ HR in yoga practitioners compared to non-yoga practitioners</td>
</tr>
<tr>
<td>Bhimani et al. 2011 (Bhimani et al. 2011)</td>
<td>Healthy non yoga practitioners (n=59)</td>
<td>Cohort study; Yogic breathings- (Kapalbhati, Ujjayi, RNB, Sitkari and Shitali)</td>
<td>2 months Pre intervention versus post intervention</td>
<td>Frequency domain: ↑ LF/Hu. ↑ HFn.u., and ↓LF/HF Time domain: No significant change</td>
</tr>
<tr>
<td>Jaju et al. 2011 (Jaju et al. 2011)</td>
<td>COPD patients (n=11); Healthy control (n=6)</td>
<td>NRCT; ANB at 5 breath/min 30 minutes /5 days week (3 months) Pre intervention versus post intervention</td>
<td>Frequency domain: No significant change in either group</td>
<td></td>
</tr>
</tbody>
</table>

**Legends:** LFnms - low frequency; HR - heart rate; BRS - baroreflex sensitivity; BR - breath rate; HFnms - high frequency power; SBP - systolic blood pressure; DBP - diastolic blood pressure; VLFms - very low frequency; HF - high frequency; RMSSD - root mean square of successive difference; pNN50 - proportion of NN50; SDNN - standard deviation of NN interval; NN50 - successive NN that differs by more than 50ms;
# Table 7.6.3 (a): Heart Rate Variability (HRV), Yoga Postures and Integrated Yoga

<table>
<thead>
<tr>
<th>Author</th>
<th>Population</th>
<th>Study Design</th>
<th>Intervention</th>
<th>Length of intervention</th>
<th>Comparators</th>
<th>Outcome HRV</th>
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<th>Jedad Scale Score for RCT</th>
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</thead>
<tbody>
<tr>
<td>Howorka et al. 1995</td>
<td>Health non-yoga practitioners</td>
<td>Multiple practices in multiple session</td>
<td>Yoga session (headstand, shoulder stand and forward bend postures); aerobic exercise; Rest</td>
<td>10 minutes each intervention</td>
<td>Baseline versus post intervention</td>
<td>Frequency domain: ↑ HFms&lt;sup&gt;2+&lt;/sup&gt; and ↓ LFms&lt;sup&gt;2±&lt;/sup&gt;/HF after yoga; No changes either after aerobic or rest</td>
<td>-</td>
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<tr>
<td>Manjunath and Telles 2003</td>
<td>Regular male yoga practitioners</td>
<td>Multiple practices in single session</td>
<td>Headstand without support (n=20); Headstand with support (n=20)</td>
<td>Single session</td>
<td>Baseline versus post intervention</td>
<td>Frequency domain: ↓ HFn.u. and ↑ LF/HF after headstand without support; Similar less significant change after headstand with support</td>
<td>↓ in HR after both postures</td>
<td>-</td>
</tr>
<tr>
<td>Melville et al. 2012</td>
<td>Sedentary healthy office employees</td>
<td>Multiple practices in multiple session</td>
<td>Chair based gentle integrated yoga; guided meditation; Control during routine office work</td>
<td>15 minutes each intervention</td>
<td>Comparison between interventions</td>
<td>Frequency domain: ↓ HFn.u., ↑ LFn.u., ↑ LF/HF during yoga compared to control session; Time Domain: ↑ in SDNN&lt;sup&gt;+&lt;/sup&gt; during yoga compared to control session</td>
<td>↓ BR&lt;sup&gt;+&lt;/sup&gt; during yoga and meditation compared to control; ↑ HR during yoga, ↓ in HR during meditation compared to control; ↓ stress scores during yoga and meditation;</td>
<td>-</td>
</tr>
<tr>
<td>Study</td>
<td>Group description</td>
<td>Intervention details</td>
<td>Frequency domain</td>
<td>Time domain</td>
<td>Heart Rate and Breathing Rate Impact</td>
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<tr>
<td>Sarang and Telles 2006 (Sarang &amp; Telles 2006)</td>
<td>Regular male yoga practitioner (n=42)</td>
<td>Multiple practices in multiple session Cyclic meditation (CM); supine rest</td>
<td>Multiple sessions Baseline versus during and post intervention</td>
<td>Frequency domain: ↓ HFn.u., ↑ LFn.u., ↑ LF/HF during postural sequences of CM; ↑ HFn.u., ↓ in LFn.u., ↓ LF/HF after CM; No significant change with supine rest</td>
<td>↑ in HR and BR during CM and ↓ in HR and BR after CM</td>
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<tr>
<td>Vempati 2000 (Vempati, RR, Telles, S. 2000)</td>
<td>Non-yoga practitioners with occupational stress (n=26)</td>
<td>Cyclic meditation with yoga philosophy including yogic management techniques</td>
<td>Multiple session 2 days Pre intervention versus post intervention</td>
<td>Frequency domain: ↑ in HFn.u., ↓ LFn.u., ↓ LF/HF, ↓ BR after yoga intervention</td>
<td>↓ BR after yoga intervention</td>
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<tr>
<td>An, Kulkarni et al. 2010 (An et al. 2010)</td>
<td>Healthy females non yoga practitioners (n= 28)</td>
<td>Cyclic meditation (CM); supine rest</td>
<td>Multiple sessions Baseline versus post intervention</td>
<td>Frequency domain: ↑ HFn.u., ↓ LFn.u., ↓ LF/HF after CM Time domain: ↑ pNN50 and RMSSD after CM; No significant change in either domain with supine rest</td>
<td>↓ HR and respectively after CM and supine rest</td>
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<td>Patra and Telles 2010 (Patra &amp; Telles 2010)</td>
<td>Regular yoga male practitioners (n 30)</td>
<td>Cyclic meditation (CM) ; Supine rest</td>
<td>Multiple session Comparison between intervention</td>
<td>Frequency domain: ↓ LFn.u., ↓ LF/HF during sleep after CM compared to supine rest; Time domain: ↑ pNN50 during sleep after CM compared to sleep</td>
<td>↓ HR during sleep after CM</td>
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<tr>
<td>Khattab et al. 2007 (Khattab et al. 2007)</td>
<td>Regular yoga practitioners (n=11)</td>
<td>Iyenger yoga, walking</td>
<td>Multiple sessions Comparison between intervention</td>
<td>Time Domain ↑ RMSSD, ↑pNN50 with yoga practice compared to walking</td>
<td>↓HR with yoga compared to walking</td>
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*HFn.u.*, *LFn.u.*, *LF/HF*, *RMSSD*, *pNN50*
<table>
<thead>
<tr>
<th>Study cited</th>
<th>Participants</th>
<th>Intervention Details</th>
<th>Duration</th>
<th>Design</th>
<th>Outcome measures</th>
<th>Improvements/Significance</th>
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<tr>
<td>Shapiro et al. 2007 (Shapiro et al. 2007)</td>
<td>Unipolar major depressive patients (n=17)</td>
<td>Cohort study</td>
<td>8 weeks</td>
<td>Baseline versus post intervention</td>
<td>Frequency domain: ↓ in LFms²</td>
<td>Improvements in the scores of depression; hostility trait anxiety and anger</td>
</tr>
<tr>
<td>Dolgoff-Kaspar et al. 2012 (Dolgoff-Kaspar et al. 2012)</td>
<td>Patients awaiting organ transplant (n=6)</td>
<td>Cohort study</td>
<td>4 weeks</td>
<td>Baseline versus post intervention</td>
<td>Time Domain: ↑ SDNN⁸, ↑RMSSD⁹ after yoga intervention compared to control period</td>
<td>Significant improvements in the scores of mood states, anxiety scores after yoga intervention compared to the control period</td>
</tr>
<tr>
<td>Papp et al. 2013 (Papp et al. 2013)</td>
<td>Participants with elevated blood pressure (n=12)</td>
<td>Cohort study</td>
<td>8 weeks</td>
<td>Baseline versus post intervention</td>
<td>Time domain: ↑ pNN50 after yoga intervention;</td>
<td>No change in BP</td>
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<tr>
<td>Shaankarappa.V. 2013 (Shaankarappa.V. 2013)</td>
<td>Non yoga practitioners (n=50)</td>
<td>Cohort study</td>
<td>90 minutes daily/6 days a week (12 months)</td>
<td>Pre intervention versus post intervention</td>
<td>Time domain: ↑ in SDNN</td>
<td>-</td>
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<tr>
<td>Singh and Telles 2009 (Singh &amp; Telles 2009)</td>
<td>Hypertensive (n=11) and diabetic patients (n= 6)</td>
<td>Cohort study</td>
<td>7 days</td>
<td>Pre intervention versus post intervention</td>
<td>No significant change in yoga group with integrated yoga in frequency and time domain in either group</td>
<td>-</td>
</tr>
<tr>
<td>Study (Year)</td>
<td>Group</td>
<td>Method</td>
<td>Duration</td>
<td>Intervention Details</td>
<td>Time domain</td>
<td>Significance</td>
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<tr>
<td>Niranjan et al. 2009 (Niranjan et al. 2009)</td>
<td>Hypertensive (n=46) and non-hypertensive (n=31)</td>
<td>NRCT</td>
<td>9 months</td>
<td>Yoga group integrated yoga practice (n=16); exercise group-warming and treadmill (n=16); Yoga + exercise (n=15); Normotensive control (n=31)</td>
<td>↑ in inter-beat interval in exercise + yoga group after intervention and in exercise group; No change in yoga group</td>
<td>↓ in SBP/DBP in exercise + yoga group</td>
</tr>
<tr>
<td>Satyapriya et al. 2009 (Satyapriya et al. 2009)</td>
<td>Non yoga females in 18-20 weeks of pregnancy (n=90)</td>
<td>RCT</td>
<td>Up to 36th week of pregnancy</td>
<td>Integrated yoga and deep relaxation for 2nd and 3rd trimester (n=45); Control with prenatal exercises and supine rest (n=45)</td>
<td>↑ HFn.u., ↓ LFn.u., ↓ LH/HF after yoga and relaxation group; Similar less significant changes in control group</td>
<td>↓ subjective stress scores yoga group</td>
</tr>
<tr>
<td>Patil et al. 2013 (Patil et al. 2013)</td>
<td>Non yoga junior athletes (n=24)</td>
<td>RCT</td>
<td>4 weeks</td>
<td>Integrated Yoga intervention-asana, pranayama relaxation and meditation (n=12); Control - routine practice</td>
<td>↑ in HFn.u., ↓ in LFn.u., ↓ in LF/HF yoga group; no significant change in control</td>
<td>-</td>
</tr>
<tr>
<td>Huang et al.</td>
<td>Healthy non</td>
<td>RCT</td>
<td>8 weeks</td>
<td>Pre</td>
<td>Frequency domain:</td>
<td>-</td>
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<tr>
<td>Year</td>
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<td>Duration</td>
<td>Pre- vs. Post- intervention</td>
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<tr>
<td>2013</td>
<td>Huang, FJ, Chien &amp; Chung (2013)</td>
<td>Yoga female practitioners (n=63)</td>
<td>Yoga practice (n=30); No intervention control (n=33)</td>
<td>intervention versus post intervention for each group</td>
<td>↑ HFn.u., ↓ LF/F in yoga group; No change in control group</td>
<td></td>
</tr>
<tr>
<td>1997</td>
<td>Bowman et al.</td>
<td>Healthy sedentary elderly &gt;62 years (n=40)</td>
<td>Integrated yoga group (n=20); Aerobic group (n=20)</td>
<td>6 weeks</td>
<td>Pre intervention versus post intervention for each group</td>
<td>Frequency domain: No change in either group</td>
</tr>
<tr>
<td>2010</td>
<td>Telles et al.</td>
<td>Post-traumatic stress symptom male patients (n=22)</td>
<td>Integrated yoga practice (n=11); Waitlist control (n=11)</td>
<td>7 days</td>
<td>Pre intervention versus post intervention for each group</td>
<td>No change in frequency and time domain in either group</td>
</tr>
<tr>
<td>2012</td>
<td>Bidwell et al.</td>
<td>Mild to moderate female asthmatic patients; (n=19)</td>
<td>Integrated yoga twice weekly with home practice(n=12); No intervention control (n=8)</td>
<td>10 weeks</td>
<td>Comparison between groups</td>
<td>Frequency domain: No change between group</td>
</tr>
<tr>
<td>2013</td>
<td>Cheema et al.</td>
<td>Sedentary healthy office employees (n=37)</td>
<td>Yoga intervention- Viniyasa - asana pranayama and relaxation (n=18); No intervention control (n=19)</td>
<td>10 weeks</td>
<td>Pre intervention versus post intervention and comparison between groups</td>
<td>No change in time and frequency domain</td>
</tr>
</tbody>
</table>

**Legends:** HFms = High frequency power; LFms = Low frequency power; HR = heart rate; SDNN = standard deviation of NN interval; BR = breath rate; pNN50 = proportion of NN50; RMSSD = root mean square of successive difference; SBP = systolic blood pressure; DBP = diastolic blood pressure;
### Table 7.6.3 (b): Heart Rate Variability (HRV), Yoga Postures and Integrated Yoga

<table>
<thead>
<tr>
<th>Author</th>
<th>Population</th>
<th>Study Design</th>
<th>Intervention</th>
<th>Length of intervention</th>
<th>Comparators</th>
<th>Outcome HRV (only statistically significant changes are reported)</th>
<th>Other outcomes</th>
<th>Jedad Scale Score for RCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chaya et al., 2008 (Chaya, MS et al. 2008)</td>
<td>Regular male yoga practitioners (n=15); male non-yoga practitioners (n=15)</td>
<td>Multiple practices in single session</td>
<td>Integrated yoga practices</td>
<td>-</td>
<td>Yoga practitioners versus non-yoga practitioners</td>
<td>Frequency domain: ↓ HFn.u., ↑ LFn.u., ↑ LF/HF in yoga practitioners compared to non-yoga practitioners</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Muralikrishnan et al. 2012 (Muralikrishnan et al. 2012)</td>
<td>Regular yoga practitioners (n=14); non-yoga practitioners (n=14)</td>
<td>Multiple practices in single session</td>
<td>Isha Yoga - (sun Salutation, static postures, purifying techniques and Shambhavi mahamudra)</td>
<td>-</td>
<td>Yoga practitioners versus non-yoga practitioners</td>
<td>Frequency domain: ↑ HFn.u., ↓ LFn.u., and ↓ LF/HF in yoga practitioners in resting state compared to non-yoga practitioners</td>
<td>No significant difference in HR²</td>
<td>-</td>
</tr>
<tr>
<td>Friis and Sollers Iii, 2013 (Friis &amp; Sollers Iii 2013)</td>
<td>Regular yoga practitioners (n=18) Metabolically matched non-yoga practitioners (n=17), aerobically fit participant (n=19)</td>
<td>Multiple practices in single session</td>
<td>Yoga practices, and Aerobic exercises</td>
<td>Single session</td>
<td>Comparison between the groups</td>
<td>Resting pNN50 higher in yoga practitioners compared to aerobic group and non-yoga practitioners.</td>
<td>Resting HR lower in aerobic group compared to yoga practitioners and non-yoga; No difference between yoga and non-yoga group; VO₂ max higher in aerobic group compared to yoga and non-yoga group;</td>
<td>-</td>
</tr>
<tr>
<td>Satin, et al. 2013</td>
<td>Regular yoga practitioners</td>
<td>Multiple practices in</td>
<td>Integrated yoga practices</td>
<td>Single Session</td>
<td>Comparison between</td>
<td>Resting HFn.u. higher in yoga practitioners and runners</td>
<td>HR lower in Yoga practitioners and</td>
<td>-</td>
</tr>
<tr>
<td>(Satin, Linden &amp; Millman 2013)</td>
<td>(n=47), Regular runners (n=46); sedentary individuals (n=52)</td>
<td>singes session with minimum 2 years’ experience; Running practice with minimum 2 years’ experience</td>
<td>groups</td>
<td>compared to sedentary; runners compared to sedentary; BR* lesser in yoga group compared to sedentary and runners</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legends:** HFn.u.* - high frequency normalised unit; LFn.u.* - low frequency normalised unit; HR* - heart rate; pNN50* - proportion of NN50; VO₂* - volume of oxygen consumption; BR* - breath rate
CHAPTER 8

An Explorative Study of Metabolic Responses to Mental Stress and Yoga Practices in Yoga Practitioners, Non-Yoga Practitioners and Individuals with Metabolic Syndrome


Introduction

Stress places a metabolic burden on homeostasis and is likened to sympathetic activity, increased energy expenditure and pathology. The yogic state is a hypometabolic state that corresponds with mind-body coherence and reduced stress. This study aimed to investigate metabolic responses to stress and different yoga practices in regular yoga practitioners, non-yoga practitioners and metabolic syndrome patients. The study reported that yoga practitioners have greater metabolic variability.
An explorative study of metabolic responses to mental stress and yoga practices in yoga practitioners, non-yoga practitioners and individuals with metabolic syndrome

Anupama Tyagi, Marc Cohen, John Reece and Shirley Telles

Abstract

Background: Stress places a metabolic burden on homeostasis and is linked to heightened sympathetic activity, increased energy expenditure and pathlogy. The yogic state is a hypometabolic state that corresponds with mind-body coherence and reduced stress. This study aimed to investigate metabolic responses to stress and different yoga practices in regular yoga practitioners (YP), non-yoga practitioners (NY) and metabolic syndrome patients (MS).

Methods: YP (n = 16), NY (n = 15) and MS (n = 15) subjects underwent an experimental protocol that comprised of different 5-minute interventions including mental arithmetic stress test (MAST), alternate nostril breathing (ANB), Kapalbhati breathing (KB) and meditation (Med) interspersed with 5 minutes of quiet resting (neutral condition (NC)). During the intervention periods continuous body weight-adjusted oxygen consumption (VO2ml/min/kg) was measured using open circuit indirect calorimetry with a canopy hood.

Results: This is the first study to report oxygen consumption (OC) in yoga practitioners during and after MAST and the first to report both within and between different populations. The results were analysed with SPSS 16 using 3x9 mixed factorial ANOVAs. The single between-subject factor was group (YP, NY and MS), the single within-subject factor was made up of the nine intervention phases (NC1, MAST, NC2, ANB, NC3, KB, NC4, Med, NC5). The results demonstrated that the regular YP group had significantly less OC and greater variability in their OC across all phases compared to the MS group (p = .003) and NY group (p = .01). All groups significantly raised their OC during the mental arithmetic stress, however the MS group had a significantly blunted post-stress recovery whereas the YP group rapidly recovered back to baseline levels with post stress recovery being greater than either the NY group or MS group.

Conclusions: Yoga practitioners have greater metabolic variability compared to non-yoga practitioners and metabolic syndrome patients with reduced oxygen requirements during resting conditions and more rapid post-stress recovery. OC in metabolic syndrome patients displays significantly blunted post-stress recovery demonstrating reduced metabolic resilience. Our results support the findings of previous randomised trials that suggest regular yoga practice may mitigate against the effects of metabolic syndrome.

Clinical trial number: ACTRN12614001075673; Date of Registration: 07/10/2014.

Keywords: Yoga, Meditation, Breathing, Metabolic syndrome, Oxygen consumption, Energy Expenditure, Metabolic rate. Stress reactivity, Stress recovery
Chapter 8

An Explorative Study of Metabolic Responses to Mental Stress and Yoga practices in Yoga Practitioners, Non-yoga Practitioners and Individuals with Metabolic Syndrome

Background
Stress has been defined as a 'nonspecific response of the body to any noxious stimulus' [1] and the stress response is associated with heightened sympathetic nervous activity and increased energy expenditure along with associated changes in heart rate, breath rate and blood pressure. Stress places a metabolic burden on homeostatic processes and if stress is severe or prolonged, it may lead to disturbed homeostasis, distress and psychophysiological dysfunction [2] with increased resting metabolic rate [3], exacerbation of metabolic dysfunction [4,5] and acceleration of aging [6] morbidity and mortality [7]. Several longitudinal studies further suggest that severe prolonged stress is associated with the development of metabolic syndrome [4,6], which is related to impaired mitochondrial functioning and metabolic inflexibility [9].

Metabolic activity, which is maximal during intense physical activity and lowest during resting conditions, increases with both psychological and physiological activity as well as with stress and many pathological conditions [7,10]. Higher oxygen consumption (OC) is seen with mental arithmetic or video gaming [11-13] and OC is reported to be higher in people with pathological conditions such as chronic obstructive pulmonary diseases [14], congestive heart failure [15], insomnia [16], anxiety [17], HIV-AIDS [18,19] as well as the individual features of metabolic syndrome such as hypertension [20,21], obesity [22,23], diabetes [24,25] and dyslipidaemia [26]. Peak oxygen consumption has also been found to be lower in people with metabolic syndrome [19,27].

While stress increases metabolic activity and disassociates physiological and psychological processes, relaxation practices tend to induce mind-body coherence or a sense of psychological and physiological equilibrium that counteracts stress by inducing a 'relaxation response' [28]. Yoga includes a range of mind-body practices that include postures, breathing, meditation and relaxation [29], and studies suggest that a single yoga session can lead to improvements in cognitive performance [30], baroreflex sensitivity, oxygen saturation [31-33], sympathetic balance (HRV) [34] and enhance recovery after stressful stimuli [35-36]. Further studies suggest that regular yoga practice can effectively mitigate workplace stress [37], examination stress [38,39], stress-induced inflammation [40], caregiver stress [41] and post-traumatic stress [42].

The stress relieving properties of yoga are associated with induction of a hypo-metabolic or 'yogic state' state that is associated with reduced psychophysiological activity and OC [43], with reduction in OC of up to 40% during specific practices [44]. This 'yogic state', which corresponds to a state of mind-body coherence, has also been described as the 'flow state' [45] and is distinct from rest [46], physical relaxation [47] and sleep [48] and may be voluntarily induced while performing fixed physiological workloads [49]. The long term practice of yoga may also enhance metabolic resilience and flexibility. Compared to non-yoga practitioners, regular yoga practitioners are reported to have reduced heart [50], breath, and metabolic rates [51,52] as well as reduced blood pressure [50,53] and lipid profiles [54]. Regular yoga practice has also been associated with improved lung function [53,55] and heart rate variability [56] with the duration of practice directly corresponding to reductions in heart rate (HR), blood pressure (BP) and respiratory rate (RR) [54] and improvements in mindfulness [57] and lipid profiles [54].

While there appears to be a clear relationship between yoga and metabolism, no studies have compared the metabolic response to mental stress in yoga practitioners and non-yoga practitioners or compared OC in yoga practitioners, non-yoga practitioners and metabolic syndrome patients during different yoga practices. To fill this gap, the following explorative study was designed to examine the metabolic responses to stress and different yoga practices and compare the responses of regular yoga practitioners, non-yoga practitioners and metabolic syndrome patients.

Methods
Study location
The study took place between November and January 2012 at the Yoga Research laboratory situated at Patanjali Yogpeeth in Haridwar, India. The study was approved by the RMIT University Human Research Ethics Committee and retrospective approval was granted by the ethics committee at Patanjali Yogpeeth.

Population
The study population involved three groups aged 18 years to 55 years all of Indian origin. The groups were:

Yoga practitioner (YP) Group
Consisted of yoga teachers, yoga therapists and yoga active persons with a minimum of 6 months yoga experience who were residents of the Patanjali Yogpeeth campus or surrounding ashrams and were involved in routine asram life. They practiced yoga for at least 90 minutes daily and were non-smokers on a strict non-alcoholic, vegetarian diet for at least 6 months.

Non-Yoga practitioner (NY) Group
Included temporary residents of Patanjali Yogpeeth and at the time of their participation were all non-smokers on a non-alcoholic, vegetarian diet. Most of the participants in this group had never practiced yoga before, but some had either practiced irregularly or recently begun yoga practice (6 days).
Metabolic Syndrome (MS) Group
Included subjects with metabolic syndrome as defined by the International Diabetic Federation [58] and diagnosed by their general practitioner and treated with regular medication or prescribed lifestyle modification. These subjects, who were not residents of the campus and had not previously practiced yoga, were asked to maintain a vegetarian diet and refrain from tobacco and alcohol 10 hours prior to their experimental session.

People with any serious medical condition or condition requiring regular analgesic medication, or who were unable to adequately perform the yogic interventions were excluded. Pregnant women and women in their menstrual period were also excluded to avoid the cyclic decrease in basal metabolic rate prior to ovulation [59].

Experimental protocol
All participants were requested to have a minimum 7 hours of sleep and avoid strenuous exercise, alcohol and analgesic medication the day before their experimental session. Participants were asked to attend wearing loose comfortable clothing and fast and abstain from tobacco and caffeine for 8 hours prior to their session. All the sessions for the YP group were conducted between 7 to 9 AM while the sessions for the NY and MS groups took place between 8 to 10 AM except for 5 NY participants who were unavailable in the mornings and had sessions conducted during the afternoon.

On attending the laboratory, participants had explained to them in their native language by the experimenter and detailed information with demonstration of the each intervention was provided. The YP were all well versed with the specific yogic interventions. Some of the NY had brief acquaintance with some practices, while none of the MS group had prior experience with yoga and were given time to practice and get acquainted with the interventions till they performed them accurately. As Hindi was the native language of most participants, the consent forms and demographic forms were all translated into Hindi language by professional translators. Reliability and validity of the translation was checked via a different group of professional translators providing back translation to English.

After providing written consent, participants were asked to empty their bladder and switch off their mobile phones. They then had their height, body weight, waist circumference, seated BP and radial artery pulse measured before commencing the experimental session. All measurements were performed by the same experimenter with participants in a recumbent position. The laboratory was maintained at a comfortable temperature of 23 degrees Celsius with subdued lighting.

Before gas exchange recording commenced, subjects were asked to relax and adjust to the environment of the canopy for 10 minutes. The experimental session lasted around 60 minutes and involved multiple phases of equal duration with intervention phases interspersed with the neutral condition of eyes open rest. The experimental sequence involved nine separate 5 minute phases, each preceded by a one minute pause (Pause) during which BP was measured and they were instructed on the next phase (Figure 1). The yogic practices were all based on traditional yoga texts with some slight variation to account for the recumbent position and the requirements of the measuring equipment.

Neutral Condition (NC)
During the neutral condition participants were instructed to breathe spontaneously, avoid movement, yawning or mental agitation and have a relaxed quiet mind.

Mental Arithmetic Stress Test (MAST)
The Mental Arithmetic Stress Test (MAST) involved participants having their eyes closed and being instructed in a crisp tone of voice to read a 4 digit number written on a piece of cardboard and to then count backwards by 3 s as quickly and accurately as possible until asked to stop.

Alternate Nostril Breathing (ANB)
The ANB phase involved subjects gently occluding alternate nostrils with their fingers as described by Niranjanananda [60] and continue this cycle rhythmically, soundlessly and effortlessly for 5 minutes until instructed to stop. The experienced yoga practitioners were informed not to perform retention during breathing cycles.

![Figure 1 Experimental sequences.](image-url)
Kapalbhati Breathing (KB)
Participants were instructed to breathe through their nostrils at around 48 BPM (0.8 Hz) and forcefully exhale by contracting their abdominal muscles and then allowing inhalation to occur spontaneously. As this type of yogic breathing can be stressful and result in dizziness or discomfort for some people, the non-yoga and MS group were suggested to continue a cycle of spontaneous breathing in the event of any discomfort.

Meditation (Med)
The meditation phase involved subjects lying with their body relaxed and still and eyes gently closed. Subjects were asked to quietly repeat the mantra ‘AUM’ at their own pace during exhalation.

Outcome measures
Anthropometric measures
Body weight and height were measured using an electronic platform scale (Gold Tec GTEP-100 K), and stadiometer (Seca-274). Waist circumference was measured with subjects standing with arms at their side, feet close together and weight evenly distributed. Measures were taken at the midpoint between the lower margin of the last palpable rib and the top of the iliac crest at the end of expiration to ensure a relaxed abdominal wall as per WHO guidelines [61].

BP measurement
Blood pressure was measured before and after every experimental condition using an automatic digital blood pressure monitor (Welch Allyn, Redding Medical, USA) with the cuff positioned on the left arm at the level of the right atrium. The BP monitor was calibrated and checked using a mercury sphygmomanometer and stethoscope as described by the British Hypertension Society [62].

Metabolic measures
This study focused on weight-adjusted OC (relative OC) which is more reliable when comparing people with different body weight [63].

VO2ml/min/kg (Relative OC) was measured continuously via indirect calorimeter using an open circuit, OC gas analyser. This calorimeter uses a canopy hood and dilution technique that allows measurements to be made with subjects breathing spontaneously or as instructed according to the study protocol without the encumbrance of a face mask, mouth piece or nose clips (Quark CPET, Italy). Before each experimental session the calorimeter was calibrated using a reference gas mixture.

Measurement of O2 consumption and CO2 production was performed at 5 second intervals. Calibration of flow was performed using a certified 3 L calibrated syringe and calibration of the O2 and CO2 gas analysers was performed prior to each experimental session using a certified calibration gas. Before each experimental session a 5 minute steady state was achieved as per previous studies [64]. The calorimeter provided both absolute and relative (per kg of body weight) values.

Results
Demographic details of the Participants (Table 1).

Statistical analysis
Data were analysed using SPSS 19. Metabolic variable-relative OC (VO2ml/min/kg) was analysed using a series of 3 x 9 mixed factorial ANOVAs. The single between-subjects factor was group (Yoga Practitioner, Non-yoga Practitioners and Metabolic Syndrome); the single within-subjects factor was made up of the nine levels of Phase (NC1, MAST, NC2, ANB, NC3, KB, NC4, MED, NC5). Any significant group by phase interactions were followed by a full analysis of simple main effects. The descriptive values of metabolic variable across nine phases in three groups are shown in Table 2.

Inferential results for metabolic variable (VO2ml/min/kg)
Figure 2 shows the pattern of changes in relative oxygen consumption (VO2/min/kg) for 3 groups over the nine experimental phases.

Statistical analysis revealed a significant phase by group interaction, $\Lambda = .11, F(16, 72) = 8.66, p < .001, \eta^2 = .66$, a significant phase main effect, $\Lambda = .04, F(8, 36) = 122.25$, $p < .001, \eta^2 = .96$, along with significant group main effect. Group, $F(2, 43) = 5.85, p = .006, \eta^2 = .21$. The pairwise comparison of the estimated marginal means for the main effect for group revealed a significant difference in relative OC between the WP group and both MS and NY groups.

Table 2 illustrates, $p$ values for pairwise mean comparisons based on the analysis of estimated marginal means with Bonferroni-adjusted $\alpha$ values revealed significant differences between the WP and MS groups in phases NC1, NC2, ANB, NC3, NC4, MED and NC5. Significant differences were also found between the WP and NY groups in phases NC1, MA, NC2, NC3, NC4 and Med.

Table 1 Demographic properties of the participants

<table>
<thead>
<tr>
<th>Group</th>
<th>Gender</th>
<th>Age (ys)</th>
<th>Weight (kg)</th>
<th>BMI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yoga practitioners</td>
<td>F = 3</td>
<td>12 ± 10</td>
<td>62 ± 7</td>
<td>211 ± 1.6</td>
</tr>
<tr>
<td>(n = 16)</td>
<td>M = 12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Yoga practitioners</td>
<td>F = 5</td>
<td>30 ± 11</td>
<td>69 ± 12</td>
<td>249 ± 4.0</td>
</tr>
<tr>
<td>(n = 15)</td>
<td>M = 10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metabolic syndrome</td>
<td>F = 3</td>
<td>41 ± 5</td>
<td>86 ± 9</td>
<td>315 ± 1.7</td>
</tr>
<tr>
<td>(n = 15)</td>
<td>M = 12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2: Means and standard deviations of VO2ml/min/kg of all three groups across nine phases

<table>
<thead>
<tr>
<th>Groups</th>
<th>NC1</th>
<th>MAST</th>
<th>NC2</th>
<th>ANB</th>
<th>NC3</th>
<th>KB</th>
<th>NC4</th>
<th>Med</th>
<th>NC5</th>
</tr>
</thead>
<tbody>
<tr>
<td>VP</td>
<td>3.6 ± 0.2</td>
<td>4.1 ± 0.2</td>
<td>3.7 ± 0.2</td>
<td>4.4 ± 0.2</td>
<td>3.6 ± 0.3</td>
<td>4.5 ± 0.2</td>
<td>3.8 ± 0.1</td>
<td>3.5 ± 0.1</td>
<td>3.6 ± 0.2</td>
</tr>
<tr>
<td>NY</td>
<td>3.8 ± 0.2</td>
<td>4.5 ± 0.2</td>
<td>4.0 ± 0.2</td>
<td>4.6 ± 0.2</td>
<td>3.9 ± 0.2</td>
<td>4.4 ± 0.2</td>
<td>4.0 ± 0.2</td>
<td>3.8 ± 0.2</td>
<td>3.8 ± 0.2</td>
</tr>
<tr>
<td>MS</td>
<td>3.9 ± 0.2</td>
<td>4.2 ± 0.3</td>
<td>4.2 ± 0.2</td>
<td>4.1 ± 0.3</td>
<td>3.9 ± 0.2</td>
<td>4.3 ± 0.2</td>
<td>4.2 ± 0.2</td>
<td>3.9 ± 0.3</td>
<td>3.9 ± 0.3</td>
</tr>
</tbody>
</table>

Groups: VP = Yoga Practitioners; NY = Non-Yoga Practitioners; MS = Metabolic Syndrome Patients.
Phases: NC = Neutral Condition; MAST = Mental Arithmetic Stress Test; ANB = Alternate Nostril Breathing; KB = Kapalbhati Breathing; Med = Meditation.

The NY group was significantly different from the MS group at NC2, ANB and NC4. Analysis of the simple main effect for phase within group revealed that the three groups differed significantly in every phase except for during Kapalbhati breathing phase 1- 'Neutral Condition 1' (NC 1), F(2, 43) = 7.97, p = .001, \( \eta_p^2 = .27 \); phase 2 - 'Mental Arithmetic Stress Test' (MAST), F(2, 43) = 3.66, p = .05, \( \eta_p^2 = .14 \); phase 3 - 'Neutral Condition 2' (NC 2), F(2, 43) = 13.34, p < .001, \( \eta_p^2 = .47 \); phase 4 - 'Alternate Nostril Breathing' (ANB), F(2, 43) = 4.14, p < .001, \( \eta_p^2 = .29 \); phase 5 - 'Neutral Condition 3' (NC 3), F(2, 43) = 7.91, p = .001, \( \eta_p^2 = .27 \); phase 6 - 'Meditation (Med)', F(2, 43) = 11.36, p < .001, \( \eta_p^2 = .33 \) and phase 9 - 'Neutral Condition 5' (NC 5), F(2, 43) = 3.82, p = .03, \( \eta_p^2 = .15 \).

Further, simple main effect analysis for group within phase revealed that all three groups varied significantly across the nine phases: Yoga Practitioners (YP), \( \Lambda = .05, F(8, 36) = 88.32, p < .001, \eta_p^2 = .95 \); Non-yoga Practitioners (NY), \( \Lambda = .10, F(8, 36) = 41.47, p < .001, \eta_p^2 = .89 \) and Metabolic Syndrome (MS), \( \Lambda = .19, F(8, 36) = 18.54, p < .001, \eta_p^2 = .80 \). The YP group demonstrated the largest variability across the nine phases, as evidenced by the higher effect size value of \( \eta_p^2 = .95 \) for the yoga group in the group within phase simple main effect, by comparisons with a figure of \( \eta_p^2 = .80 \) for the NY group and .80 for the MS group. This effect size value is derived from the
An Explorative Study of Metabolic Responses to Mental Stress and Yoga practices in Yoga Practitioners, Non-yoga Practitioners and Individuals with Metabolic Syndrome

Table 3 P values for pairwise comparison of estimated marginal means of VO2mL/min/Kg by group

<table>
<thead>
<tr>
<th>Phases</th>
<th>All phase</th>
<th>YP vs MS</th>
<th>YP vs NY</th>
<th>NY vs MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated marginal means</td>
<td>.003*</td>
<td>.01*</td>
<td>.15</td>
<td></td>
</tr>
</tbody>
</table>

YP = Yoga practitioners; NY = Non-Yoga Practitioners; MS = Metabolic Syndrome Patients.
* = p value significant.

### Corresponding F ratios, which also demonstrated considerably more variance in the YP group F (8, 36) = 82.86, p < .001, compared with both NY group F (8, 36) = 99.68, p < .001 and the MS group F (8, 36) = 18.42, p < .001. Across all phases, the yoga practitioner group was significantly different from both the NY group, p < .017 and the MS group, p < .01.

At the level of pairwise comparison for simple main effect of groups within phases, several significant differences were evident in the three groups in different phases (Table 5 describes p values of comparison of each intervention with pre and post phase).

There is also some evidence indicating that YP group exhibited a higher level of recovery that the other two groups. The effect size of each group associated with the change from phase 2 to phase 3 revealed a value of d = 0.37 for the MS group, d = 2.05 for the NY group and d = 1.98 for the YP group. The changes from phase 2 to 3 was not significant for MS group but was significant at p = .009 and p < .001 respectively for NY and YP groups.

### Discussion

This observational study found that regular yoga practitioners had significantly less OC and greater variability in their OC across all phases compared to non-yoga practitioners or metabolic syndrome patients. While the YP group had lower baseline OC, their OC increased substantially in response to the active interventions and fully recovered back to baseline levels during resting periods. These findings related to metabolic activity are consistent with previous studies that have found regular yoga practitioners have a lower basal metabolic rate compared to non-yoga practitioners [51,52] with greater recovery from stress [65,66].

This is the first study to report OC in yoga practitioners during and after mental arithmetic stress and the first to measure metabolic reactivity and recovery both within and between different participant populations involving metabolic syndrome patients. Our study is also the first to examine OC in yoga practitioners using indirect calorimetry with a ventilatory hood. While other studies have examined yoga using similar indirect calorimetry methods [67], the use of a ventilatory hood is reported to be less stressful than calorimetry that uses a mouthpiece or mask [68,69] and hence is likely to have facilitated greater relaxation amongst our participants and therefore more accurate results.

While our study used a rigorous experimental method, it is an observational study rather than a randomised clinical trial and the differential effects between groups may have been due to factors other than their history of yoga practice. The selection of our study population and protocol may have also introduced some bias. For example there were numerous differences between the groups with the MS group being on average 10 years older than the other groups and the baseline OC being lowest in the YP and highest in the MS groups. Furthermore, there were some smokers in the MS group and none in the YP group and the YP group were all well versed with the yoga practices and were also involved in routine ahrm life, which included activities such as meditation, yoga philosophy discussions,
meetings with spiritual leaders and teachers, Ayurvedic diet and structured daily routines. Some of the YP group were also familiar with the laboratory testing, whereas the NY and MS groups were not well versed with the yoga techniques or the laboratory and were only temporary ashram residents or resided outside the ashram where they were subjected to the stresses of everyday life. This may have led to the NY and MS groups being less relaxed than the YP group and less able to perform the active practices correctly. Some aspect of the yoga interventions also lacked uniformity, for example there was a difference in the breath rate between groups during Kapalabhati breathing, due to the advanced nature of these practices, which are difficult to learn and perform by novices. Comparing these practices in novice and advanced practitioners may therefore produce unreliable results unless the practices are specifically paced to achieve uniform breath rates across groups. The timing and sequencing of the different experimental phases may have also influenced the results, as they were of relatively small duration with only brief rest periods that may not have allowed full recovery between the phases. Due to these limitations we have limited our discussion to the analysis of the mental arithmetic stress test, which occurred first in the experimental sequence, and have not discussed the responses to the ANB, KB or meditation practices.

It is evident that mental arithmetic induced a metabolic burden on our participants, with all groups having significantly raised OC during the mental arithmetic phase. Mental arithmetic stress is widely used to elicit β-adrenergic sympatho-adrenal responses in laboratory conditions [12,70] and cardiovascular reactivity to mental arithmetic-induced stress is reported to be unrelated to personality type [71], yet more pronounced in subjects with high BP [72]. Cardiovascular reactivity to mental stress is also reported to be an independent risk factor for features of metabolic syndrome including hypertension and insulin resistance [70,73,74] as well as for atherosclerosis [75] and future cardiovascular risk [76]. However, cardiovascular reactivity is not always associated with negative health outcomes and may be adaptive and reflect behavioural flexibility, energy mobilisation and effective coping rather than pathology [75] as indicated by reports of a negative association between cardiovascular reactivity and obesity, depression and self-reported health [77].

We found that while mental stress placed a metabolic burden on all groups, the MS group had a significantly blunted post-stress recovery. This supports previous suggestions that recovery responses may be a better predictor of subsequent cardiovascular risk than stress-induced reactivity [78-81]. Our finding that the YP group had a greater post-stress recovery in oxygen consumption than either the NY or MS group are consistent with reports of greater recovery in heart rate in meditators compared to non-meditators after watching a stressful film [65] and greater recovery in self-reported measures after watching negative emotion-evoking slides [66]. Our results further support suggestions that individuals who are able to rapidly return their cardiovascular activity to baseline following a stressful event are more likely to have better cardiovascular health [75].

While the biological mechanism linking stress responses and cardiovascular diseases and mortality is poorly understood, there is evidence to suggest that cardiovascular responses to psychological stress are associated with increased allostatic load [82] and thus poor cardiovascular health [4]. This may be indicated by changes in the autonomic nervous system, hypothalamic-pituitary-adrenal axis and metabolic, immune, cellular and physiological and psychological changes that include endothelial dysfunction, shortened telomere length and less focused thought processes [5,83-85]. Slower recovery from psychological stress may also reflect a greater allostatic load and reduced sympatho-adrenal flexibility [82], while yoga and meditation appears to enhance adaptability and post-stress recovery [44]. It has been further suggested that the relaxation response may be associated with improved mitochondrial energy production and utilisation that promotes mitochondrial resilience through upregulation of ATPase and insulin function [86].

In our study the YP group had a greater metabolic response to mental arithmetic stress than the other groups as well as having a more rapid recovery. This is consistent with previous studies that suggest that yoga practices enhance autonomic regulatory reflex mechanisms associated with stress [87] and improve autonomic function, pulmonary function and metabolic function [88-90]. Single yoga sessions have also been shown to reduce HR and BP in sedentary individuals [91], healthy non-yoga practitioners [35], as well as in patients with hypertension [92-94] and congestive heart failure [95]. Regular yoga practice has been further shown to down regulate the HPA axis and sympatho-adrenal pathways with reduction in catecholamine and cortisol levels [29,41], and improve immune response [38,87], vascular function [96] and melatonin secretion [97,98]. Regular yoga practice has also been shown to contribute to cognitive improvement [29] physical relaxation [99] and reductions in emotional distress [100] and anxiety [101].

The results of this study suggest that regular yoga practitioners have enhanced metabolic resilience with reduced basal metabolic demands and enhanced recovery after stress while metabolic syndrome patients have higher basal metabolic demands and blunted post-stress recovery. These results are consistent with other studies that report that regular yoga practice enhances metabolic function.
and improves obesity [102], dyslipidemia [103], hyperglycemia [104], hypertension [105,106] and metabolic syndrome [107-109].

**Conclusion**

Yoga practitioners have reduced oxygen requirements during resting conditions and greater metabolic flexibility compared to non-yoga practitioners and metabolic syndrome patients. Yoga practitioners are also better able to respond to and recover from the increased metabolic burden due to mental arithmetic stress, while metabolic syndrome patients have significantly blunted post-stress recovery. Further, long term studies are needed in order to establish, if regular yoga practices have an influential role in reducing resting metabolic demand. In future, studies should incorporate longer intervention phases to investigate the metabolic reactivity and recovery to stress and to determine if yoga practices are able to enhance metabolic resilience in metabolic syndrome patients.

**Competing interests**

The authors declare that they have no competing interests.

**Authors’ contributions**

AT and MC designed and conceived the study, AT performed the data collection under supervision and guidance of ST. AT and JR performed the statistical analysis and AT and MC wrote the manuscript and all authors reviewed the draft. All authors read and approved the final manuscript.

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Chapter 8
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CHAPTER 9

Heart Rate Variability ‘HRV’ During Yoga Practices and Mental Stress in Yoga Practitioners, Non-yoga Practitioners and People with Metabolic Syndrome ‘MetS’

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Evidence-Based Complementary and Alternative Medicine
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Introduction

Heart Rate Variability (HRV) and respiratory sinus arrhythmia (RSA) are directly associated with autonomic flexibility, positive affective states and well-being and inversely associated with pathological and psychological conditions. This study explored the relationship between HRV, mood states and flow experience in different populations during mental arithmetic stress test and yoga practices. The study reports that yoga practitioners have heightened experience of flow and greater autonomic variability.
Heart Rate Variability ‘HRV’ During Yoga Practices and Mental Stress in Yoga Practitioners, Non-yoga Practitioners and People with Metabolic Syndrome ‘MetS’

9.1 Abstract

Heart Rate Variability (HRV) and respiratory sinus arrhythmia are directly associated with autonomic flexibility, positive affective states and well-being and inversely associated with physiological and psychological stress and pathological conditions. Various yoga practices are reported to enhance autonomic activity, mitigate stress responses and benefit stress-related clinical conditions, yet the relationship between autonomic activity and psychophysiological responses during yoga practices and stressful stimuli has not been widely explored. We performed a laboratory-based, observational study to explore the relationship between HRV, mood states, flow experience and absolute oxygen consumption in regular yoga practitioners (YP), non-yoga practitioners (NY) and people with metabolic syndrome (MetS) during Mental Arithmetic Stress Test (MAST) and various yoga practices. We found that the MAST placed a physiological and metabolic burden in all participants with the YP group showing the greatest reactivity and the most rapid and complete recovery, while the MS group had significantly blunted recovery. The YP group also reported a heightened experience of flow and positive mood states and lower oxygen consumption compared to NY and MS groups as well as having a higher vagal tone at all resting conditions and greater autonomic variability across experimental phases. This suggests that regular yoga practitioners have greater homeostatic capacity and autonomic, metabolic and physiological resilience with a heightened ability to dampen parasympathetic activities during mental and physiological stress and then rapidly return parasympathetic activity to baseline. Further studies are now needed to determine if regular yoga practice may improve autonomic flexibility in non-yoga practitioners and metabolic syndrome patients.

KEYWORDS: Meditation, autonomic reactivity, pranayama, mental arithmetic stress, flow experience
9.2 Background

Stress has been defined as a non-specific response to noxious stimuli (Selye 1956) and is reflected through increased sympathetic activity and concomitant vagal withdrawal. Severe and sustained stress responses can lead to autonomic inflexibility and negative affective states and create a physiological burden that increases sympathetic dominance, energy demands and allostatic load (McEwen 1998a). In contrast, autonomic flexibility, which can be indicated by vagal activity (Thayer et al. 2012), reflects the dynamic interplay between the individual and environment and the resilience with which psychophysiological processes are able to meet environmental challenges and achieve homeostasis. When challenges and capacity are equally matched the ‘flow state’ is said to occur (Csikszentmihalyi 2008), which is a dynamic state associated with positive affective states and optimal performance as well as psychological health and wellbeing (Thayer et al. 2012). Reduced autonomic or psychophysiological flexibility reduces the capacity to adjust to environmental challenges and may lead to impaired mitochondrial function and the development of conditions such as metabolic syndrome ‘MetS’, accelerated aging and cardiovascular disease (Thayer et al. 2012).

HRV, can be used as a measure of autonomic function and is operationalised using the R-R interval of the ECG (QRS peak) and analysed either in the time or frequency domain. Time domain measures at rest reflect respiratory sinus arrhythmia ‘RSA’ and cardiac parasympathetic outflow. In the frequency domain, the low frequency band (LF, 0.15 to 0.04 Hz) provides a strong measure of sympathetic activity as well as indicating vagal tone (Task Force 1996). The high frequency band (HF, 0.15-0.4 Hz) includes the range of normal respiration (9-24 breath/min) and provides an index of vagal activity that is positively associated with aerobic fitness, resilience to stress and physiological and psychological flexibility (Thayer et al. 2012), and negatively associated with stress (Jarczok et al. 2013) and negative affective states. The HF band also reflects RSA, and when increased RSA occurs independently of respiration rate and is coupled with decreases in HR it can be used as an indicator of cardiac vagal tone (M. 2007). However, as RSA is closely related to respiratory
parameters, alterations in respiration can seriously confound the association between RSA and vagal tone and this has important implications for yoga research as some yoga breathing practices such as Kapalbhati involve rapid breathing, while other yoga practices such as yogic relaxation and meditation may result in dramatically reduced respiration.

Mental stress exerts influence on HRV and RSA oscillations and the Mental Arithmetic Stress Test (MAST) is routinely used in laboratory conditions to elicit β-adrenergic sympatho-adrenal responses (Carroll, Phillips & Balanos 2009; FlaaAksnes, et al. 2008). Mental stress is reported to enhance sympathetic activity, alter sympathovagal balance and reduce total HRV power (ms²) (Malliani et al. 1991) and cardiovascular reactivity to mental stress is reported to be more pronounced in subjects with higher BP (Flaa et al. 2006) and in individuals with certain personality or behaviour traits such as type A (Chida & Hamer 2008) and type D behaviours (Razzini et al. 2008). The ‘reactivity hypothesis’ suggests that hyperactive individuals may have more frequent surges of sympathetic activity and larger cardiovascular changes in response to mental stress and that such reactivity is an independent risk factor for the features for metabolic syndrome such as hypertension and insulin resistance (Carroll et al. 2012; Carroll, Phillips & Balanos 2009; Carroll et al. 2011; FlaaAksnes, et al. 2008; FlaaEide, et al. 2008; Flaa et al. 2006) as well as atherosclerosis (Heponiemi et al. 2007) and future cardiovascular events (Chida & Hamer 2008; Chida & Steptoe 2010).

While the reactivity hypothesis has had some experimental support (Heponiemi et al. 2007), the suggestion that sympathetic activation is at the core of the stress response overlooks the role of autonomic balance and the complex adaptive allostatic response system that involves both turning on and turning off responses (McEwen 1998b). The reactivity hypothesis therefore does not consider recovery processes that are predominantly mediated by parasympathetic activities (Heponiemi et al. 2007). Recent evidence strongly suggests that chronic low parasympathetic tone accompanied by low parasympathetic reactivity is linked to maladaptive stress responses and therefore provides a link between deficient vagal inhibitory influences and various health and disease states (Porges 1992; Thayer et al. 2012). In contrast, high vagal tone is suggested to enhance autonomic flexibility and generate an ‘upward spiral’ so that the capacity to adapt to stress is enhanced leading to
positive affective states and overall wellbeing and resilience (Porges 2011; Souza et al. 2007).

Mind-body interventions tend to facilitate autonomic flexibility, enhance self-regulation and induce relaxation that is characterised by parasympathetic dominance (Taylor, AG et al. 2010) and increased HRV (Takahashi et al. 2005; Tang et al. 2009; Wu, SD & Lo 2008). Yoga, includes a wide range of mind-body practices that include postures, breathing and meditation/relaxation that are reported to counteract stress (Granath et al. 2006; Yadav et al. 2012) and a range of stress-related disorders(Innes, Bourguignon & Taylor 2005). Regular yoga practice appears to enhance homeostatic processes and physiological efficiency and foster the attainment of a hypometabolic or ‘yogic state’. This state appears to indicate the attainment of mind-body coherence or a sense of psychological or physiological equilibrium and that is different from rest (Dillbeck & Orme-Johnson 1987), physical relaxation (Fokkema 1999) and sleep (Elson, Hauri & Cunis 1977). Regular yoga practice also appears to enhance parasympathetic activity and compared to non-yoga practitioners, regular yoga practitioners are reported to have lower heart rate (HR), breath rate (BR), blood pressure (BP) (Bharshankar et al. 2003), metabolic rate (Chaya, M et al. 2006) and higher HRV (Muralikrishnan et al. 2012). A single session of yoga is also reported to lead to improvement in sympatho-vagal balance (Huang, FJ, Chien & Chung 2013), cognitive performance (Gothe et al. 2013), recovery after stressful stimuli (Sharma, G, Mahajan & Sharma 2007) and baroreflex sensitivity with better oxygen saturation and reduced chemoreflex sensitivity (Mason et al. 2013). Though there appears to be a clear relationship between yoga and autonomic function, no study has yet explored HRV during different yoga practices and stressful stimuli in different populations. To fill this gap, the following laboratory study was designed to examine HRV during stressful stimuli and different yoga practices and compare the HRV and psycho-physiological responses of regular yoga practitioners, non-yoga practitioners and metabolic syndrome patients.
9.3 Research Methodology

This study used the same data set as reported in the previous chapter of this thesis.

Study location, Study Population, experimental sequence and protocol details as well as demographics (anthropometrics) are reported in Chapter 8 of this thesis.

9.4 Outcome Measures

A range of outcome measures were used including autonomic and psychometric measures.

9.4.1 Autonomic and Metabolic Measures

An ECG recording was performed using a two channel ECG Biopac Student Lab system (MP 45, Biopac System INC, USA), together with gas-exchange measures using open circuit indirect calorimeter with canopy hood (Quark CPET, Italy). Before any recordings commenced, subjects were asked to relax and adjust to the conditions inside the canopy for approximately 10 minutes.

HRV was measured using a standard 2 limb configuration and pre-gelled electrodes (Tyco Healthcare Germany) on skin that had been previously abraded, cleaned and dried. The data acquisition sample rate was set to 1000 Hz with a low pass filter at 35 Hz and a high pass filter at 0.5 Hz. The detection of RR wave was performed offline by Labchart 7 (AD Instrument, Australia) and HRV was analysed in both the time domain and frequency domain using HRV analysis program ‘KUBOIS (Version 2)’ developed by the Biomedical Signal Analysis Group (University of Kuopio, Finland) (Tarvainen et al. 2009).

9.4.2 Psychometric Measures: Profile of Mood States and Flow Scale

Profile of mood states ‘POMS’ is a self-administered instrument to assess mood state in wide range of population (Wyrwich & Yu 2011) that provides detail of 6 theorised mood states on 5 point scale ranging from ‘not at all’ to ‘extremely’.
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For calculating total mood disturbance (TMD), the 5 mood states (1) Tension/anxiety ‘T’, (2) depression/dejection ‘D’, (3) anger/hostile ‘A’, (4) fatigue/inertia ‘F’, and (6) confusion/bewilderment ‘C’ are added (T+D+A+F+C) and sixth (6) vigor/activity ‘V’ is subtracted from the sum.

The Flow Scale provides state and trait measures of optimal psychological experience through the Flow State Scale (FSS), which is a state measure, and the Dispositional Flow State (DFS), which quantifies ‘flow’ as a trait.

9.5 Data Extraction

The HRV power spectrum was obtained using Fast Fourier Transformation analysis and the following specific bands were studied: low frequency band (LF) (0.04 – 0.15 Hz) and high frequency band (HF) (0.15 – 0.4 Hz). The high frequency band for Kapalbahti breathing, which involved breathing at a rate of approximately 48-breath/min, was extended to include frequencies up to 1 Hz. The LF band and HF band were expressed in normalised units and the sympathovagal balance was expressed using the LF/HF ratio. The components analysed from the time domain analyses were: RMSSD – ‘the root mean squares of successive differences’; pNN50- ‘proportion of NN50 (the number of interval differences of successive NN intervals greater than 50 milliseconds)’; and HR. Respiratory signals were measured continuously during each experiment session using the Biopac system via a respiratory belt and transducer placed at the abdominal level.

9.5.1 Statistical Analysis

Data for all of the outcome variables were screened for data entry errors and tested for their suitability for parametric analysis. Pooled versions of multiple imputed outcomes were used in all analysis. Data were analysed using SPSS 19. Patterns of missing values were examined and it was found that the conditions for multiple imputation were met (Graham 2009). All analyses were assessed against a critical per comparison error rate of $p < .05$ in order to compensate for potential inflation of the family wise error rate.
HRV variables were analysed in the frequency and time domains using a series of 3 x 9 mixed factorial ANOVAs. The single between-subjects factor was group (Yoga Practitioner, Yoga Naïve and Metabolic Syndrome patients); the single within-subjects factor was made up of the nine phases. Any significant group by phase interactions were followed by a full analysis of simple main effects.

The two psychometric measures, the POMS and the Flow State Scale were analysed using a series of 3x2 mixed factorial ANOVAs. The single between-subject factor was phase (Pre intervention, post intervention). Any significant group by phase interaction were followed by a full analysis of simple main effect.

9.6 Results

Table 9.6 presents the descriptive values of HRV, respiratory and metabolic variable across the nine phases in three groups.

9.6.1 Inferential Results for HRV, Cardiorespiratory and Metabolic Variables

The significant phase-by-group interaction was evident in all frequency and time domain variable as well as respiratory rate and oxygen consumption (Figure 9.6.1). The YP group demonstrated the largest variability and this was evident in the simple main effect analysis test in all HRV frequency and time domain variables and in respiratory and metabolic variables, revealing that the effect size ($\eta^2_p$) for YP group within phase was higher than for any of the other two groups. Table 9.6.1 (a) illustrate the P-values for pairwise comparisons of estimated marginal means for main effect for group and Table 9.6.1 (b) illustrate the P-values of pairwise mean comparisons based on the analysis of estimated marginal means with Bonferroni-adjusted $\alpha$ value in all variables of frequency domain, time domain respiratory rate and oxygen consumption.

9.6.1.1 Frequency Domain Analysis

LF (nu) and HF (nu)- revealed significant phase by group interaction, $\Lambda = .37, F(16, 72) = 2.95, p = .001, \eta^2_p = .71$. Simple main effect analysis
revealed that YP group displayed most labile responses over the nine phases was evident for the YP group, $\Lambda = .24, F(8, 36) = 16.67, p < .001, \eta^2_p = .69$, with no significant effect evident for NY group and MS group.

**LF/HF ratio** - revealed significant phase by group interaction, $\Lambda = .50, F(16, 72) = 1.8, p = .04, \eta^2_p = .66$. YP group displayed the most labile responses over nine phases, YP group, $\Lambda = .27, F(8, 36) = 11.78, p < .001, \eta^2_p = .71$; NY group, $\Lambda = .63, F(8, 36) = 2.63, p = .04, \eta^2_p = .43$; with no significant effect evident for MS group.

**9.6.1.2 Time Domain analysis**

Similar significant results were evident in all variables

**For RMSSD**, a significant phase by group interaction, $\Lambda = .29, F(16, 72) = 2.60, p = .001, \eta^2_p = .70$ was evident. Simple main effects analysis revealed that YP group displayed more labile results over nine phases, YP group, $\Lambda = .21, F(8, 36) = 17.46, p < .001, \eta^2_p = .71$; NY group, $\Lambda = .33, F(8, 36) = 9.42, p < .001, \eta^2_p = .63$ and MS group, $\Lambda = .59, F(8, 36) = 3.01, p = .01, \eta^2_p = .41$.

**For pNN50**, a significant phase by group interaction, $\Lambda = .17, F(16, 72) = 6.11, p < .001, \eta^2_p = .82$ was evident. The most labile responses over nine phases was evident for YP group, $\Lambda = .11, F(8, 36) = 37.97, p < .001, \eta^2_p = .79$, followed by NY group, $\Lambda = .16, F(8, 36) = 23.92, p < .001, \eta^2_p = .67$ and, MS group, $\Lambda = .42, F(8, 36) = 6.11, p = .006, \eta^2_p = .52$.

**For Breath Rate**, a significant phase by group interaction, $\Lambda = .18, F(16, 72) = 4.72, p < .001, \eta^2_p = .68$ was evident. Similar to other variables, YP group demonstrated largest variability across nine phases compared to other two groups, YP group, $\Lambda = .07, F(8, 36) = 66.47, p < .001, \eta^2_p = .93$; NY group, $\Lambda = .09, F(8, 36) = 42.38, p < .001, \eta^2_p = .90$ and MS group, $\Lambda = .17, F(8, 36) = 21.57, p < .001, \eta^2_p = .82$. 
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For VO₂, a significant phase by group interaction, $\Lambda = .41$, $F(16, 72) = 9.72$, $p< .001$, $\eta_p^2 = .88$ was evident. Similar to other variables, YP group demonstrated largest variability across nine phases compared to other two groups, YP group, $\Lambda = .09$, $F(8, 36) = 76.24$, $p <.001$, $\eta_p^2 = .91$, NY group, $\Lambda = .11$, $F(8, 36) = 52.38$, $p <.001$, $\eta_p^2 = .80$ and MS group, $\Lambda = .22$, $F(8, 36) = 21.34$, $p <.001$, $\eta_p^2 = .77$.

9.6.2 Inferential Results for Profile of Mood states and Flow state Scale

Figure 9.6.2 presents the different POMS domains and Flow scale results for each group before and after the intervention period. Table 5 presents the $p$ values for comparison of flow and each mood state before and after the intervention period.

Based on the scoring of POMS a significant phase main effect was evident in all mood states, however significant phase by group interaction was evident only for vigor, $\Lambda = .86$, $F(2, 43) = 3.59$, $p = .03$, $\eta_p^2 = .14$ and depression, $\Lambda = .81$, $F(2, 43) = 4.99$, $p = .01$, $\eta_p^2 = .19$. For those variables, where a significant group by phase interaction was not evident, a significant phase effect was seen: tension, $\Lambda = .67$, $F(1, 43) = 20.75$, $p< .001$, $\eta_p^2 = .32$, confusion, $\Lambda = .80$, $F(1, 43) = 10.23$, $p= .003$, $\eta_p^2 = .33$, fatigue, $\Lambda = .79$, $F(1, 43) = 11.72$, $p= .001$, $\eta_p^2 = .39$, and anxiety, $\Lambda = .67$, $F(1, 43) = 20.36$, $p< .001$, $\eta_p^2 = .32$.

The significant phase main effect was also evident in TMD- total mood disorder; $\Lambda = .34$, $F(1, 43) = 81.52$, $p< .001$, $\eta_p^2 = .65$ and Flow scale also $\Lambda = .76$, $F(1, 43) = 13.67$, $p= .001$, $\eta_p^2 = .24$. Pairwise comparison based on estimated marginal means revealed a significant difference for the YP group from the NY and MS at $p=001$ and $p<.001$ respectively. The marginal means associated with the significant phase main effects for all the variable of POMS and flow scale indicated that the change was in the hypothesised direction of improvement.
9.7 Discussions

This explorative study evaluated HRV, mood states, psychological flow experience and oxygen consumption in response to mental stress and yoga practices in yoga practitioners ‘YP’, non-yoga practitioners ‘NY’ and people with metabolic syndrome ‘MS’. Our results revealed that the YP group had greater autonomic variability and higher vagal activity than either the NY or MS groups across all phases. The YP group also had higher vagal tone and lower absolute oxygen consumption at rest and were better able to respond to and recover from mental arithmetic stress. Our results further revealed that while all groups had improvements in their mood and a greater experience of flow after the intervention period compared to baseline and that these findings were more pronounced in the YP group compared to the other groups.

This study is the first to report HRV in yoga practitioners during a MAST and is the first to compare HRV responses to stress between yoga practitioners and non-yoga practitioners. In our study the MAST placed a cardiovascular and metabolic burden on all participants leading to corresponding changes in cardiovascular variables, HRV and oxygen consumption. The pattern of recovery however, was different in each group. The YP group displayed the greatest post-mental stress recovery while the NY displayed post-stress recovery that was less than the YP group and greater than the MS group. The MS group were the least able to recover from mental stress and their HRV and metabolic variables displayed only minimal, blunted post-stress recovery. These findings suggest that yoga practitioners have a heightened autonomic and cardiovascular flexibility with a greater ability to recover from mental stress than non-yoga practitioners, and that such flexibility is reduced in metabolic syndrome patients.

The high reactivity to mental stress shown by the YP group in our study is consistent with two previous studies that reported higher systolic BP reactivity in anticipation to giving a public talk (Wenneberg 1997) and higher HR in anticipation to watching a stressful film (Goleman & Schwartz 1976) in regular meditators compared to non-meditators. These studies suggest that regular meditators experienced more stress in anticipation to a stressful event and this has been suggested to represent a defensive reaction that facilitates appropriate
coping (Wenneberg 1997). These studies however, did not report on stress reactivity during the actual stressful event, so it is unclear from these studies how meditators and non-meditators respond to actual stress. Our study builds on these studies by demonstrating that yoga practitioners have greater autonomic reactivity, flexibility and resilience than non-yoga practitioners with a greater ability to react to, and recover from, stressful events.

Autonomic flexibility includes dimensions of reactivity and recovery mediated by vagal pathways, which can be reflected by measures of RSA or HRV during spontaneous breathing. Such flexibility indicates a more efficient physiological system and a more responsive and dynamic link between the peripheral, autonomic and central nervous systems (Thayer, Yamamoto & Brosschot 2010). ‘Polyvagal theory’ suggests that periods of stress functionally remove the potent ‘vagal break’ from the heart and thereby facilitate increased metabolic output to fuel the sympathetic fight and flight reaction. Our findings suggest that yoga practitioners have a heightened ability to dampen their parasympathetic activity during challenging situations and then rapidly increase their parasympathetic activity to baseline to affect rapid recovery.

Stress recovery is less commonly reported than reactivity and has not been previously reported in studies of yoga and therefore our study is the first report that regular yoga practitioners display enhanced post-stress recovery in cardiovascular, autonomic and metabolic variables. This finding is consistent with a previous report of greater recovery in HR in meditators compared to non-meditators after watching a stressful film (Goleman & Schwartz 1976). The ability to rapidly recover from stress has important clinical implications because a rapid return to homeostasis ensures the greatest flexibility to respond to any future stress and any residual response can contribute to the development of chronic disease. This has been highlighted by two meta-analyses that link sluggish post-stress recovery to poor cardiovascular health (Chida & Hamer 2008; Chida & Steptoe 2010), while rapid cardiovascular recovery is associated with increased vagal tone, efficient HR regulation (Heponiemi et al. 2007) and overall cardiovascular health (Porges 2011; Thayer et al. 2012).
While the mechanism through which yoga practices influence physiology is not clear, it is possible that regular yoga and meditative practice enhances psychophysiological processes that efficiently restore homeostatic capacity. It is reported that regular yoga practitioners have higher RSA at rest (Muralikrishnan et al. 2012) and lower basal metabolic rate (Chaya, M et al. 2006) and that regular yoga practice down-regulates the HPA axis and sympatho-adrenal pathways with reduction in catecholamine and cortisol levels (Danucalov et al. 2013; Granath et al. 2006) and enhances vagal dominance compared to physical exercise (Bowman, Clayton & Murray 1997; Khattab et al. 2007).

The combination of stimulating movements, focused attention, natural mindfulness and mind-body coherence that is integral to all yoga practices may play an important role in enhancing vagal activity. The conscious regulation of breathing that is an inherent part of yoga practices may further assist in regulating the stress response. Regular yoga breathing practices have also been shown to improve autonomic, pulmonary and metabolic function (Abel, Lloyd & Williams 2013; Acharya, R. U. et al. 2006; Telles, Nagarathna & Nagendra 1995) and normalise baroreflexes, which may become impaired with aging, cardiac disease and hypertension (Brown, R. P. & Gerbarg 2005a). The conscious control of breathing patterns can affect ANS and HRV (Lehrer, PM, Woolfolk & Sime 2007) and can accounts for 40% variance in mood states (Streeter et al. 2012).

The practice of yoga, which uses a focus on the breath to integrate the functions of the mind and body has been likened to the ‘flow state’, which is described as a form of ‘eustress’ or desirable state of positive arousal caused by the perception of subjective control with maximum physiological efficiency and the down-regulation of all functions that are irrelevant for task fulfilment (Csikszentmihalyi 2008; Peifer 2012; Selye 1983). In our study, the experimental intervention resulted in an enhanced mood and increased experience of flow in all participants, with the YP group experiencing the most pronounced effect. This suggests that the MAST and yoga practices served as a form of positive stress to which the YP group were best able to respond and that regular yoga practice may increase the capacity to respond to stress with enhanced mental and physiological control and efficiency.
While our study used a rigorous experimental method, the selection of our study population may have introduced some bias due to the yoga practitioners having more familiarity with the various yoga practices and the laboratory setting. Thus the NY and MS groups may have been less relaxed than the YP group and less able to perform the active practice correctly. During our study participants were also required to lie recumbent under the ventilatory hood of the indirect calorimeter. This may have facilitated greater relaxation among participants than would normally occur during a MAST or seated yoga practices. The timing and sequencing of the different experimental phases may have also influenced the results, as each active period was of relatively small duration with only brief rest periods that may not have allowed full recovery between the phases. Due to these limitations we have limited our discussion to the analysis of the mental arithmetic stress test, which occurred first in the experimental sequence, and have not discussed the responses to the ANB, KB or meditation practices in any detail.

Further studies are now needed to investigate autonomic flexibility in response to stress and yoga interventions, and future studies may be well placed to focus on specific stressors or single yoga practices rather than an elaborate sequence of practices. Future studies are also needed to investigate autonomic flexibility, stress responses and metabolic efficiency in metabolic syndrome patients and examine any training effects of various yoga practices in different populations.

9.8 Conclusion

Regular yoga practitioners were found to have higher vagal tone at all baseline states and higher variance to autonomic and metabolic measures during all active interventions with greater autonomic reactivity to, and recovery from, mental arithmetic stress. The yoga practitioners further demonstrated a greater homeostatic capacity which was reflected by greater autonomic flexibility and resilience. Further long term studies are now needed in order to establish if regular yoga practice may improve autonomic flexibility in non-yoga practitioners and metabolic syndrome patients.
### Table 9.6: Mean and Standard Deviations of HRV and Respiratory Variables of all three groups across Nine Phases

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**Group:** YP = Yoga Practitioners; NY = Non-Yoga Practitioners; MS = Metabolic Syndrome Patients; Phases: NC = Neutral Condition; MAST= Mental Arithmetic Stress Test; ANB= Alternate Nostril Breathing; KB= Kapalbhati Breathing; Med= Meditation

Comparison of each intervention with pre and post phase: *p<0.05; **p<0.01; ***p<0.001
Table 9.6.1 (a): *P* values for pairwise comparison of estimated marginal means by group for all phases

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<td>NS</td>
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Group: YP = Yoga practitioners; NY = Non-Yoga Practitioners; MS = Metabolic Syndrome Patients

NS= Not significant; *= significant difference
Table 9.6.1 (b): P values for pairwise comparisons of estimated marginal means with Bonferroni-adjusted $\alpha$ values for three groups across nine phases

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**Group:** YP = Yoga Practitioner; NY = Non-Yoga Practitioner; MS= Metabolic Syndrome patients;  
**Phases:** NC=Neutral Condition; MAST= Mental Arithmetic stress Test; ANB- Alternate Nostril Breathing; KB= Kapalbhati Breathing; Med= Meditation; 
**NS**= Not Significant; * = Significant difference.
Chapter 9
Heart Rate Variability ‘HRV’ during Yoga Practices and Mental Stress in Yoga Practitioners, Non-yoga Practitioners and People with Metabolic Syndrome

HRV (Time and Frequency Domain), Cardiorespiratory and Metabolic Measures (Figure: 9.6.1)

- LF (nu)
- HF (nu)
- LF/HF Ratio
- RMSSD
- pNN50
- Heart Rate
- Breath Rate
- Oxygen consumption

Phases:
- NC = Neutral Condition
- MAST = Mental Arithmetic Stress Test
- ANB = Alternate Nostril Breathing
- KB = Kapalbhati Breathing
- Med = Meditation

Group:
- Yoga Practitioners (YP)
- Non-Yoga Practitioners (NY)
- Metabolic Syndrome Patients (MS)

Error Bars:
- YP
- NY
- MS

$\$ indicates significant difference between YP vs MS
\$ indicates significant difference between YP vs NY
€ indicates significant difference between NY vs MS
Heart Rate Variability ‘HRV’ during Yoga Practices and Mental Stress in Yoga Practitioners, Non-yoga Practitioners and People with Metabolic Syndrome

Profile of Mood States (POMS) & Flow State (Fig:9.6.2)

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* indicates significant pre vs post

Pattern of Change in POMS and Flow Scale for Three Groups Pre- and Post- Intervention
Chapter 10
Overall Discussion

10.1 Introduction

This final discussion seeks to draw together and highlight the principal findings of the various reviews and studies conducted and discuss their implications. This discussion is organised into 4 parts (a) overview of the key findings (b) insight of the research in terms of the literature (c) limitations of the studies (d) implications for future research. The significance of this research is the contribution it makes to the body of knowledge in the area that identifies the link between yoga practices countering stress and how they contribute to the dynamic flow that leads to psychophysiological flexibility, mitochondrial efficiency and resilience.

As previously mentioned in chapter 1, the overall aim of this thesis were:

- To perform systematic reviews of research undertaken explaining specific yoga practice and their effects on hypertension, oxygen consumption (OC) and heart rate variability (HRV) in different populations.
- To investigate the, metabolic, cardiovascular and autonomic patterns of stress responsivity in regular yoga practitioners, non-yoga practitioners and individuals with metabolic syndrome.
- To investigate the psychophysiological effects of different yoga practices and document the cardiovascular, metabolic and autonomic changes with different yoga practices.
- To investigate the psychological states of regular yoga practitioners and examine and compare the flow and mood states in different populations.

The key findings of the 5 studies will be discussed in relationship to how dynamic approaches of yoga improve self-regulatory capacity through the inhibition of stress responses. This in turn enhances parasympathetic control that reduces allostatic load and promoting an upward spiral of physiological coherence, flexibility, relaxation and wellbeing.
10.2 Key Findings of the Reviews, Explorative study and their Clinical Relevance

This section will discuss the key findings of the five studies undertaken in this research and will also highlight their implications for clinical relevance. This section will specifically discuss that multimodal components of yoga affect cognitive, emotional and behavioural regulatory system, potentially influence and improving peripheral and psychological functioning both during practice and in midst of the day (daily life stresses).

Firstly, the three reviews undertaken (Chapter 5-7) in this thesis investigated the intervening effects of yoga on BP, OC and HRV. Secondly the included studies in these respective reviews were divided according to type of yoga intervention such as Pranayama, Asana/integrated yoga, meditation/relaxation that analysed the specific effects of these practices on psychophysiology.

These reviews reported that yoga practices have profound effect on BP, OC and HRV. The reviews further reported that yoga practices have training effect and facilitate adaptation. These effects were however associated with both during short term (immediate after the practice) as well as the long term yoga practices.

Further, these reviews identified type of yoga practices, outcome measures, study duration, study design and small sample size as source of heterogeneity with most of the studies performed involving male yoga practitioners that lacked comparison groups. Further among many confounders, primarily most of the studies involved healthy population that make difficult to generalize the results on larger clinical population group and secondly most of these studies were conducted in non-western clinical research context, primarily in India where yoga is widely accepted within prevailing culture.

Firstly, in the explorative studies, the yoga practitioners during the complete experimental session displayed greater variability in metabolic and cardio-autonomic responses which were indexed through OC and HRV. Secondly,
yoga practitioners demonstrated increased OC and vagal withdrawal associated with mental stress displaying higher reactivity and they returned swiftly to baseline following the stressful event. This suggests that psychophysiological flexibility may be surrogated by the efficient ability to respond to stress with heightened cardiovascular and metabolic activities that include sympathetic activation and withdrawal of vagal brake (Porges & Furman 2011).

10.2.1 Clinical Relevance of the Findings

The reviews and explorative interventional study together advocate that the skillset tools of yoga – postures, breathing and meditation reduce prolonged and acute response to stress that promote homeostatic processes across the bodily system. This thesis further reports that yoga alters the degree to which events are perceived stressful and the synergistic effects of yoga hold promise as therapeutic intervention in health promotion. Yoga practice modulates the process of stress reactivity and associated autonomic activities both in terms of acute forms (during and immediately) or by shifting a physiological set point from baseline reactivity over repeated long term practice (Chaya, M et al. 2006; Chaya, M & Nagendra 2008). This change in dynamic homeostatic responsivity is attributable to a form of skilful optimization of autonomic control mediated through vagal complex that keep arousal at lower levels, helping practitioner stay relaxed with fewer efforts and facilitate recovery and restoration of bodily system under chronic stress (Streeter et al. 2012).

Additionally this research supports the notion that irrespective of techniques and styles, yoga modulates behaviour and induces cognitively supported positive affective states that appear to facilitate swift adaptability. These adaptive responses are maintained through coherent self-regulatory processing that may serve to enhance psychophysiological flexibility and induce the relaxation response that may ultimately contribute to improve mitochondrial energy production with efficient oxidative phosphorylation (Bhasin et al. 2013) and enhanced telomere length (Epel, E et al. 2009).

Furthermore, the stress reducing effects of yoga may lead to conservation of cognitive resources and less prolonged negative emotions- such as anger,
anxiety, and negative mood with enhanced attentional stability. This may further
lead to peripheral effects such as vasodilation, modulation in baroreceptor
control (reduction in BP) and more efficient cardiac functioning and metabolic
efficiency (Tyagi & Cohen 2014; Tyagi et al. 2014). Speculations have also been
made that yoga practices may have vital influence on many more innervating
complex system with obvious potential to maximize repair and restoration after
stress and that may promote resilience (Kuntsevich, Bushell & Theise 2010).
These wide ranging effects that include cognitive, emotional, physiological and
metabolic effects and their relationship to specific yoga practises require further
elaboration and investigation.

The thesis so far also explains that multiple tools of yoga applied for self-
development influence self-regulatory processing across multiple organ system.
These tools appear to develop the ability in the practitioner to switch self-
regulatory activities towards efficient physiological functioning with minimum
energy utilization (Tyagi & Cohen 2013; Tyagi et al. 2014) that usually results
from the cultivation of effortless flow of attention (Thayer & Lane 2000). Hence
attentional stability is critical in health and wellbeing (Epel, E et al. 2009).

The protective mechanism of yoga initiates the efficient bidirectional
interaction and integration of high level brain network and low level brain
networks along with profound influence on periphery that may emerge as change
in chronic illness schema (Tyagi & Cohen 2014). There have been suggestions in
the recent literature that mind-body interventions such as yoga may promote
self-regulation that function through both, top-down attentional mechanism and
bottom-up mechanism via ascending pathways and that involve stimulation of
various somato-, viscero-, and chemo- sensory receptors (Taylor, AG et al.
2010).

The discussion on top-down and bottom-up pathways promoting self-
regulation with yoga and meditative practices are beyond the scope of this
thesis and has been reported elsewhere (Gard et al. 2014; Taylor, AG et al.
2010). The further discussion is restricted and only highlights the correlation of
yoga and attentional stability that facilitates self-regulatory activities along with
the plausible role of vagal complex that may enhance functional capacity and psychophysiological flexibility.

10.3 Yoga Aids in Self-Regulation

The modern yoga tends to synergise varied aspects of skillset tools that could vary from pure meditative to pure physical in nature. The behaviourally and emotionally oriented ethical precepts are the central aspect of these varied styles of yoga and appear to be critical to cognitive refinement and intentional/self-control. The substantial research articulates that hallmark of efficient behavioural conciliation is sustained attention mediated through self-regulation that reflects the ability to modify psychological and physiological responses to best match the environmental demands (Telles & Singh 2013; Thayer & Lane 2000). Parallel increases in behavioural reconciliation are the increase in self-regulation and are associated increase in parasympathetic nervous system status (Porges & Furman 2011). This autonomic input manifested in cardiac variability corresponds to competent vagal complex (Thayer & Lane 2000).

In the paradigm of yoga, diversity in yoga practices and styles are an important factor as it meets the need of widely differing yoga aspirants. In such cases yoga therapists or yoga teachers may have the opportunity to use a style and specific practices that are safe and appropriate for the patient population or may fulfil the individual need (Sherman 2012). The diversity in yoga may refer to steadying the mind (Pratap, Berrettini & Smith 1978) that mainly involves stillness in posture with intense focus on breath and /or meditation in motion (Khalsa et al. 2009) or cyclic meditation (Sarang & Telles 2006) that promotes a highly focused attention on bodily movement emphasising on periods on stimulation followed by periods of relaxation. All these practices commonly underscore the refinement and development of attentional stability and consistently have been reported to have considerable input in positive physiological modulation (Andrieu et al. 2009; Arora & Bhattacharjee 2008; Telles et al. 1994). These varied practices are ultimately reported to achieve the same results such as a calm, relaxed mental state and focused attention with efficient metabolic and cardiovascular activities (Telles & Singh 2013; Tyagi & Cohen 2013, 2014).
The powerful connotation of attentional stability develops the capacity in the practitioner to rapidly disengage from the object that has seized the attention and re-engage or fix the attention in the object of focus without deliberative efforts. This adaptive goal directed behavioural flexibility enhance the ability to filter and prioritise the flow of information leading to better allocation of psychophysiological resources, and greater ability to inhibit incorrect task related responses and improved performance (Salmon et al. 2009; TellesYadav, et al. 2013). This research also supports the notion that long term yoga practices generate better coping strategies, positive appraisal skills and faster recovery that facilitate restorative processes that partially may be mediated through sustained attention.

In addition there appears the research suggesting that attentional stability emerging form dynamic balance between challenges and capability contribute to optimal performance in the task in varied life domains and occurs as psychological flow experience (Csikszentmihalyi 2008). This experience which is frequently associated with sports performance (Csikszentmihalyi 2008) and music performance (Khalsa et al. 2009) is correlated to physiological activation in such a way that down regulates all bodily functions that are irrelevant to task fulfilment (Peifer 2012). A corollary to this view is that the flow state allows practitioner to switch attention on a meaningful task without deliberative efforts resulting in improved performance through right concentration and yoga practices are likely to be conducive in achieving the flow state and is vagally dominated (See section 4.6.1) (Tyagi et al. 2014).

The depth and degree of attention is a major concern, as the optimal experience resulting from effortless sustained attention may result in extending humans potentials (see section 4.6). So far the findings of this research also underpin that yoga facilitates self-regulation promotes emotional and behavioural flexibility that result in heightened positive mood states and greater experience of flow. Hence it is speculated that yoga practices synthesise the mind and body entity through attentional efforts and appear to generate the powerful unique capacity that yields psychophysiological efficiency associated with optimised cardiovascular, metabolic and autonomic functions.
10.4 Yoga Aids in Psychophysiological Flexibility

The key ingredient to optimal health appears to be psychophysiological flexibility however it is a slippery construct to define. Psychophysiological flexibility can be best described as the swift adaptability which contributes to the integrated positive psychological and physiological responses maintained through efficient interdependent behavioural and peripheral regulatory system (Kok & Fredrickson 2010). The psychophysiological flexibility referring to neurovisceral integration involves number of interdependent dynamic channels such as cognition, emotion, behaviour and physiological as well as immune system, all innervating at system and cellular level (Thayer & Lane 2009).

In the realm of yoga, psychophysiological flexibility may be best explained through a system-approach—that undertakes holistic consideration of the body as an extraordinary complex system of interacting parts, ‘a whole that is greater, that is far beyond the examination supplied by assembled pieces’ (Kuntsevich, Bushell & Theise 2010). Psychophysiological flexibility may unfold several interconnected transduction pathways through which yoga practices induce efficiency and harmony that optimizes the physiological functioning such as (1) increasing environmental demand to meet the challenges (fight and flight response), (2) reduces allostatic load (repair the physiological system) (3) readily induce calm a state consistent with metabolic demand - promote restoration of physiological set point to normal.

The repertoires of benefits emerging from yoga practices are attributable to efficient psychological and physiological system that may reduce allostatic burden (Arora & Bhattacharjee 2008; Kuntsevich, Bushell & Theise 2010; Streeter et al. 2010) are typically embodied in neurovisceral integration (Thayer & Lane 2000). The psychophysiological flexibility may also include the functional domains of metabolic resilience and recent speculations have that yoga techniques improving oxidative capacity in skeletal muscle, decrease glycogen utilization via oxidative enzymes that may further improve mitochondrial function (Akhtar, Yardi & Akhtar 2013). Despite limited number of studies, these studies consistently reveal that regular yoga practices initiate efficient glucose disposal under insulin stimulated conditions (Hunter et al. 2013; Jain et al. 1993;
Manjunatha et al. 2005). In resonance with these outcomes, a subsequent study involving yoga practitioners demonstrated efficient metabolic switch from fat oxidation (resting condition) to reliance on glucose oxidation during the period of *Kapalbhati* breathing (at 60 breath/min) and these practitioners readily switched back to reliance on fat oxidation during the periods followed by breathing practice (Telles & Singh 2011). These results are indicative to metabolic flexibility facilitated through mitochondrial efficiency.

Hence it is speculated that regular yoga practices may restore cellular homeostasis, by facilitating adaptation and compliance in skeletal muscle to develop the capacity *to fuel oxidation to fuel availability* (Nolan 2013, Pg 28). Increased glucose uptake by skeletal muscle during yogic breathing indicates β-adrenergic sympathetic stimulation that increases energy consumption (van de Weijer et al. 2013) that may be largely mediated by vagal withdrawal.

Similarly, in this research, yoga practitioners revealing large transient increase in metabolic demand with exposure to stressful stimuli followed by lower metabolic demand during resting condition may reflect metabolic flexibility through up-regulating of ATP’s and insulin function (Bhasin et al. 2013). This on the other hand demonstrated two opposing behavioural responses of vagal complex. In response to stress there was efficient mobilization of metabolic resources to meet the external demand (fight and flight response). Whereas after elimination of stress with heightened recovery the physiological system maintained visceral homeostasis (calm state consistent with metabolic demand). Hence it is speculated that yoga practices channelize psychological, physiological and metabolic regulatory processing that may be indicative to psychophysiological flexibility mediated through potent vagal system.

### 10.5 The mechanistic Functional Framework

In order to identify the essence of yoga practices achieving dynamic balance across homeostatic regulatory activities that enhances psychophysiological flexibility, it is essential to understand the mechanistic pathways. However there are several overarching frameworks involving different physiological portals that suggest the mechanism associated with yoga interventions. The explanation
of these potential mechanisms and pathways is beyond the scope of this thesis and has well been summarized elsewhere (Brown, R. P. & Gerbarg 2005b; Jerath et al. 2006; Kuntsevich, Bushell & Theise 2010; Streeter et al. 2012). However the following section will provide a concise outline of some of these conceptual frameworks.

Breathing is one the most important aspects of yoga practice and this can be better understood from ancient yoga text, *Hatha Yoga Pradipika* (see section 4.4.3). The description here is as follows

When the breath (used interchangeably with prana or subtle life energy) moves, the mental forces move; when the breath is steady, the mental forces are without movement....... by this practice the yogi attains steadiness........ and hence should regulate the breath (Muktibodhananda & Saraswati 2005, Chapter 2, Verse 2).

Breathing is the only autonomic function that can be easily and voluntarily controlled; stress, emotion and cognitive processes influence breathing and simultaneously breath rate and depth greatly influence on parasympathetic activities (Berntson et al. 1997). Further there are reports suggesting that yoga breath retention periods may result in both increases and decreases in metabolic rate (Tyagi & Cohen 2013) and alter heart rate (Telles & Desiraju 1992). Researchers therefore have articulated that specific yogic breathing patterns can be used to stimulate PNS, sympathetic nervous system (SNS) and introceptive impulses that may have widespread effects on brain functions and periphery.

Brown and Gerber (2005) with a neurophysiological model, have described that during yogic breathing stretch receptors in the alveoli, baroreceptors, chemoreceptors and sensors throughout the respiratory structure send information about the state and activity of the respiratory system through vagal afferents and brainstem rely stations to other CNS structure where they influence perception, cognition emotion regulation, somatic expression and behaviour (Brown, R. P. & Gerbarg 2005b). With the improved tone of the vagus nerve, the autonomic nervous system moves towards healthier and dynamically balanced homeostatic activities with higher variability/flexibility in end organs (Porges 1992).
Further, consistent with this model are the reports suggesting that coherence and cardiovascular resonance may occur with yogic slow breathing at around 6 BPM (0.1Hz) and mantra chanting (BernardiSleight, et al. 2001) that stimulate vagal activities with increases in amplitude of RSA. These modulations result from intra-thoracic pressure and baroreceptor stimulation (Mason et al. 2013) contribute to BP reductions and CVD improvements (Innes, Bourguignon & Taylor 2005; Tyagi & Cohen 2014). Further, Tyagi and Cohen (2014) have speculated that that the similar resonance effect that may stimulate vagal nerve may also occur with Resperate device that specifically focus on slow breathing at around 6 breath/min (Tyagi & Cohen 2014).

These resonant effects which have clinically therapeutic implications also occur with rhythmic muscle tension (Lehrer, P et al. 2009; Vaschillo, EG et al. 2011). Further using magnetic resonance imaging, a study reported that periods of OM chanting resulted in significant hypo-activate amygdalar response at limbic area that inhibits SAM activities through stimulating vagal pathways (Kalyani et al. 2011) and vagal nerve stimulation is a suggestive treatment method in several stress related mental disorders.

Additionally acknowledging and extending the neurophysiological model, Streeter and colleague (2012) in their landmark hypothesised theory based on empirical investigations of magnetic resonance imaging (Streeter et al. 2007; Streeter et al. 2010), revealed that yoga based practices improve under-activity of PNS and GABAergic activities through stimulation of the vagus nerves and that reduce allostatic load in several chronic diseases (Streeter et al. 2012). Thus this research conceptualises that yoga leads to organised cardio-autonomic, vascular and metabolic responses serving to facilitate relaxation and calm state that results from efficient organised variability between the number of interdependent physiological organs (Thayer & Lane 2007).

Furthermore, Kuntsevich and colleagues (2010), in a useful model pursued the understanding of how the biological system as a whole is modulated by yogic practices. The model conceptualizes the involvement of parallel four possible interdependent transduction pathways: humoral signaling, nervous
system, cell trafficking and bioelectromagnatism with yoga practices. However the author reported that some of the pathways such as humoral signaling and nervous system have been extensively investigated with yoga practices whereas other have not (Kuntsevich, Bushell & Theise 2010). Hence in order to completely understand the mechanism with yoga practices, there is the need for further investigation that involve throughout real-time analysis of the functional domains of genomics, proteomics and metabolomics.

10.6 Limitations and Future Directions

Each study presented in this thesis has its limitation and these have been mentioned in the relevant chapters and those limitations are not repeated here. There are a number of general common limitations regarding the three reviews and including explorative interventional study that may restrict the scope of this thesis and the breadth potentials of yoga practice. This section will describe the general limitations in context to the research studies undertaken in this thesis as well as the limitations as reported in the other reviews.

This thesis identifies that among the many confounders in the outcomes measures of the studies included in the reviews, the treatment protocols primarily focusing on physical and mental benefits evaluated therapeutic potential of yoga under optimal circumstances (laboratory based interventions). In a similar manner the explorative interventional study undertaken in this research was designed and conducted in laboratory settings. Although the laboratory based scientific studies serve as proof of concept in determining the efficacy of yoga. These studies allow investigators to document, accurately and successfully the complex behavioural processes and has been the long tradition in many fields such as psychology and physiology. The quest of these studies identifying mechanism that can explain the cognitive, psychological and physical benefits of practising yoga provides validity to yoga practices. However, in these scientific studies yoga researches, mostly with the goal directed investigations, fit the straight jacketed box of modern scientific methods and try to examine a single yoga pill for each ill (Bhavanani 2012).
The scientific studies appear to hamper the therapeutic potentials of yoga as they are generally without real world application and mostly focus on a single aspect of yoga. The scientific studies of laboratory settings restrict the frequency, duration and style of a specific yoga session as it is performed during a community based settings. Even some yoga interventionists are unsatisfied with the current research strategy and some have implied that yoga is beyond conventional scientific study in that ‘yoga practice operates outside the rules of linearity and casualty’ (Hagins & Khalsa 2012).

Whereas in order to build the evidence base for yoga as a natural healing modality that takes the whole person into account- mentally, physically and spiritually, it is important to investigate interpersonal dynamics of the practitioners. It is being recognised widely that for yoga to become recognised as a health intervention for treating health globally, yoga interventions need to move towards community based setting to reach wide range of people. However it is challenging but it is far from impossible.

The community based sessions typically focus on each aspect of yoga and are designed in such way that they provide uniqueness to yoga and ultimately results in the whole. For example, the yoga practitioners mostly can flow seamlessly through the different limbs of yoga in one session. Hence these classes of studies (community based) focusing on effectiveness of therapeutic values may allow a much broader treatment protocol.

However, currently yoga interventionists lack valid methods and tools to describe their interventions. Studies on yoga often include some combinations of yoga according to Panajali’s eight limbs. The reviews that have examined the efficacy of yoga interventions on stress and cardiovascular risk factors have generally concluded that yoga is beneficial for health, with many reviews noting inconsistent or inconclusive results. A number of authors have suggested that heterogeneity of the studied interventions owing to the many different types of yoga practiced based on each teacher’s training and philosophy, may account for inconsistent findings.

With increased attention to the quality of methods used, yoga research appears to enter a more mature phase. Without adequate information and valid
tools it is impossible to determine whether discrepancies remain due to methodological aspects such as different components like asana or meditation or length or intensity of the sessions. The investigators are articulating some of the issues around bridging yoga therapy and yoga research together.

In recent years interventionists have identified design limitations and have recommended further studies with more appropriate design before suggesting yoga as a treatment option for relieving stress. Further in an effort to develop standard descriptions of yoga intervention protocols, Sherman identify domains that should be addressed in any yoga efficacy study. These domains include style, does and delivery of yoga, components of the yoga intervention, specific class sequences, modifications, selection of instructors, facilitation of home practice and measurement of intervention fidelity over time (Sherman 2012).

Since yoga is complex in nature and to appropriately exploring the complex experience of yoga practice and attributing the meaning to the subtle changes associated with physical and cognitive dimensions such as participants’ subjective experience, body awareness and evaluation of the self may be better addressed with qualitative approach. Qualitative research strives to explore participants’ complex subjective experiences during the intervention and how she or he gives meaning to these experiences.

With this it could be speculated that yoga research is at the intersection of therapeutic scientific studies and applied research. The goal of therapeutic yoga is to narrow down the anatomical and physiological mechanisms and to understand cause and effect of in pure, logical, deterministic way. While, the qualitative research refers to be more applied and programmatic in the real world. In order to integrate yoga in to clinical settings the health benefits of practising yoga have to be rigorously documented. Researchers have to find an entry point that may enforce the conventional medical community to open the doors more widely to yoga therapy.

10.7 Final Conclusion

This thesis has helped to clarify that yoga practices hold promise as a complementary therapeutical intervention for pathogenic conditions and have
profound effects on BP, OC and HRV. This highlights that yoga practices effectively combat stress and stress related diseases and may positively influence many effects of metabolic syndrome. Yoga practices efficiently reconcile behaviour, cognition and emotion that are mediated through sustained attention and in turn enhance ability to modify psychological and physiological responses inducing relaxation. This leads to increased performance reflected though heightened flow experience and positive mood states.

The stimulating and relaxing periods of yoga practices foster psychophysiological resilience that may counter stress and variety of chronic conditions. Regular yoga practitioners appear to have an increased self-regulatory capacity that is suggestive to increased psychophysiological flexibility and may counter stress in a variety of chronic conditions. Hence yoga practices are worthy of inclusion in clinical settings. With higher coherence among psychophysiological system these practices may lead to an upward spiral of health and well-being and hence are worthy of inclusion in clinical settings. Further studies need to design study protocol with longer interventional duration, follow up periods and that may also include the interpersonal dynamic changes.


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Appendices


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Perceived environmental stress is mediated by the central nervous system and triggers neuroendocrine and autonomic nervous system activation. The immune response can be altered by signals from autonomic nerve fibers that directly synapse with immune cells and by circulating catecholamines released from the adrenal medulla. Further alteration can be produced by secretory products (hormones and neuropeptides) released from pituitary and endocrine target glands (adrenal cortex, thyroid, ovaries and testes). In turn, feedback (dashed lines) from immune cells products (cytokines) can modulate endocrine and central nervous system actively by either humoral or neuronal communication network.

*SNS = Sympathetic Nervous System; PNS = Parasympathetic Nervous System*

Appendix: 2

Pathways by which prefrontal cortex influences Heart Rate

Schematic diagram showing the pathways by which the prefrontal cortex might influence control of HR

The prefrontal, cingulate, and insula cortices from interconnected network with bidirectional communication with amygdala. The amygdala is under tonic inhibitory control via prefrontal vagal pathways to intercalated cells in the amygdala. The activation of the central nucleus of the amygdala (CeA) inhibits the nucleus of the solitary tract (NTS), which in turn inhibits inhibitory caudal ventrolateral medullary (CVLM) input to rostral ventrolateral medullary (RVLM) sympatho-excitatory neurons and simultaneously inhibits vagal motor neurons in the nucleus ambiguous (NA) and the dorsal vagal motor nucleus (DVN). In addition, the CeA can directly activate the sympatho-excitatory neurons in the RVLM.

### Appendix: 3


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<td>Presence of</td>
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<td>Waist</td>
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<td>Waist</td>
<td>Waist hip ratio ≥ 0.9 in men; 0.85 in women or BMI ≥30 kg/m&lt;sup&gt;2&lt;/sup&gt;</td>
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<tr>
<td>obesity**</td>
<td>women or BMI ≥30 kg/m&lt;sup&gt;2&lt;/sup&gt;</td>
<td>circumferencē ≥ 102 cm for men; ≥88 cm for women</td>
<td>circumferencē ≥ 94 cm for men; ≥ 80 cm for women</td>
<td>BMI 25 Kg/m&lt;sup&gt;2&lt;/sup&gt;</td>
<td>circumferencē ≥ 102 cm for men; &gt;88 cm for women</td>
<td>depending on ethnicity or BMI &gt;30 kg/m&lt;sup&gt;2&lt;/sup&gt;</td>
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<td><strong>High Density</strong></td>
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<td>≤ 40 mg/dl</td>
<td>≤ 39 mg/dl for men and women</td>
<td>≤ 40 mg/dl for men; ≤ 50 mg/dl in women</td>
<td>≤ 40 mg/dl for men; ≤50 mg/dl in women</td>
<td>≤ 40 mg/dl for men; ≤50 mg/dl in women</td>
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<td>≥ 140/90 mmHg</td>
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<td>≥ 100 mg/dl</td>
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<td>Albumin excretion ≥ 20µg/min or albumin to creatinine ratio ≥30 mg/g</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
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</table>

**Table: 3.2.2** This table summarises the clinical characteristics, diagnostic criteria, cut off points/_threshold with core components of Metabolic Syndrome as acknowledged in the definitions of the international organisations

Appendix: 4

Notice of Approval of Amendment

Date: 1 September 2011
Project number: 21/10
Project title: Psycho physiological outcomes of supine and seated interventions
Risk classification: More than low risk
Investigator: Anupama Tyagi
Expiry: 31 December 2011

Project amended on 1 September 2011:
- Change to data collection method
- Collection of data from participants in India

As described in amendment request dated 25 August 2011

Terms of approval:

1. Responsibilities of investigator
   It is the responsibility of the above investigator to ensure that all other investigators and staff on a project are aware of the terms of approval and to ensure that the project is conducted as approved by HREC. Approval is only valid whilst investigator holds a position at RMIT University.

2. Adverse events
   You should notify HREC immediately of any serious or unexpected adverse effects on participants or unforeseen events affecting the ethical acceptability of the project.

3. Plain Language Statement (PLS)
   The PLS and any other material used to recruit and inform participants of the project must include the RMIT university logo. The PLS must contain a complaints clause including the above project number.

4. Amendments
   To amend any approved documents or other aspects of the approved project (including changes in personnel) requires the submission of a request for amendment form to HREC. Amendments must not proceed without approval from HREC. Substantial variations may require a new application.

5. Annual reports
   Continued approval of this project is dependent on the submission of an annual report.

6. Final report
   A final report must be provided at the conclusion of the project. HREC must be notified if the project is discontinued before the expected date of completion.

7. Monitoring
   Projects may be subject to an audit or any other form of monitoring by HREC at any time.

8. Retention and storage of data
   The investigator is responsible for the storage and retention of original data pertaining to a project for a minimum period of five years.


AlProf Barbara Polus
Chairperson
RMIT HREC

cc: Dr Peter Burke (Ethics Officer/HREC secretary)

K:\R and R\Research Office\Governance\RMIT Ethics\HREC\Applications database\2019\21-1921-19 amendment August 2011.docx
Appendix: 5

Prescribed Consent Form For Persons Participating In Research Projects Involving Tests and/or Medical Procedures and Interviews, and Questionnaires or Disclosure of Personal Information

Portfolio
School of
Name of participant:
Project Title:

Science Engineering and Health

Psycho-Physiological and Metabolic Changes with Different Yoga Practices

Name(s) of investigators:
(1) Anupama Tyagi
(2) Prof Marc Cohen
(3) Dr. Shirley Telles

Email: anupama.tyagi@rmit.edu.au; Ph.: Email: marc.cohen@rmit.edu.au
Email: shirleytelles@panil.com

1. I have received a statement explaining the tests/procedures involved in this project.
2. I consent to participate in the above project, the particulars of which - including details of tests or procedures and interviews or questionnaires have been explained to me.
3. I authorise the investigator or his or her assistant to use with me the tests or procedures referred to in 1 above and to interview me or administer a questionnaire.
4. I acknowledge that:
   (a) Having read Plain Language Statement, I agree to the general purpose, methods and demands of the study.
   (b) The possible effects of the tests or procedures have been explained to me to my satisfaction.
   (c) I have been informed that I am free to withdraw from the project at any time and to withdraw any unprocessed data previously supplied (unless follow-up is needed for safety).
   (d) The project is for the purpose of research and/or teaching. It may not be of direct benefit to me.
   (e) The privacy of the personal information I provide will be safeguarded and only disclosed where I have consented to the disclosure or as required by law.
   (f) The security of the research data is assured during and after completion of the study. The data collected during the study may be published, and a report of the project outcomes will be provided to ................. (researcher to specify). Any information which will identify me will not be used.

Participant’s Consent

Participant: ___________________________ Date: ___________________________
(Signature)

Witness: ___________________________ Date: ___________________________
(Signature)

Participants should be given a photocopy of this consent form after it has been signed.

Any complaints about your participation in this project may be directed to the Executive Officer, RMIT Human Research Ethics Committee, Research & Innovation, 6th Floor, GPO Box 24310, Melbourne 3001 - The Telephone number is (03) 9925 3221.
Details of the complaints procedure are available from the above telephone.
Appendices

Appendix: 6

Psycho-Physiological outcomes of sealed & Suppure Interventions

1. Anupama Tyagi
   Email: anupama.tyagi@rmit.edu.au

2. Marc Cohen
   Email: marc.cohen@rmit.edu.au

3. Shirley Telles
   Email: shirleytelles@gmail.com

1. This protocol includes sealed and suppurative interventions.

2. This appendix contains the following sections:
   (a) A discussion on the application of the principles outlined.
   (b) A detailed examination of the experimental setup.
   (c) A summary of the results obtained from the experiments.
   (d) A discussion on the implications of the findings.
   (e) A discussion on the limitations of the study.
   (f) A discussion on the future directions of research.

3. The supplementary material includes:
   (a) A detailed list of references.
   (b) A glossary of terms.
   (c) A list of abbreviations.
   (d) A list of symbols.

4. The appendix concludes with a discussion on the significance of the findings and their implications for future research.
Appendix: 7

RMIT Human Research Ethics Committee

Prescribed Consent Form for Use in Research Projects Involving the Taking and Recording of Personal Images of Participants (Photos and Videos)

College/Portfolio
Science, Engineering and Health

Name of participant: __________________________

School of
Health Science

Project Title: Psycho Physiological Outcomes of Supine and Seated Interventions

Name of investigator: (1) Anupama tyagi Email: anupama.tyagi@rmit.edu.au

Senior Supervisor (2) Prof. Marc Cohen Email: marc.cohen@rmit.edu.au

Second Supervisor (3) Dr. Shirley Telles Email: shirleytelles@gmail.com

1. I have received a statement explaining the recording of my image for the above project.

2. I consent to participate in the above project, the particulars of which—including details of the recording of images—have been explained to me verbally and in the written project description.

3. I authorise the investigator or his or her assistant to record images of me.

4. I understand that:

(a) I am giving consent to have my image taken for the purpose of … [Explain purpose]
(b) That not all taken images will be used in this project
(c) That I am giving permission to have my image taken

- [ ] But any identifying features must be disguised
  …or…

- [ ] My personal image will be published or presented without any attempt made to disguise my identity

(d) That my image will be taken

- [ ] But my personal image may be altered when published
  …or…

- [ ] My personal image may not be altered or used out of context without my approval

(e) These images will be published in a report/thesis/project to RMIT University.
(f) Any used or unused personal images from this project will be destroyed upon completion of the project, including electronic images, which shall be deleted
(g) I am free to withdraw from the project at any time and to withdraw images of me that have been previously supplied prior to any publication of the report.
(h) The project is for the purpose of research. It may not be of direct benefit to me.
(i) Unless otherwise agreed copyright for a resultant image will remain with the main investigator in this project.

Participant’s Consent

Participant: __________________________ (Signature) Date: __________________________

Witness: __________________________ (Signature) Date: __________________________

Participants should be given a photocopy of this consent form after it has been signed.

Human Research Ethics Committee, November 2008
Psycho-Physiological Outcomes of seater and supine interventions

न्यूरॉनłe परियोजना मे भाग लेने हेतु सूचना फार्म

प्रकारण विवरण-
(1) नाम ........................................................................................................................................
(2) ईमेल/सम्पर्क संख्या ........................................................................................................
(3) जन्मतिथि ........................................................................................................................
(4) लिंग ....................................................................................................................................
(5) वजन ....................................................................................................................................
(6) आयु .....................................................................................................................................

प्रश्न-प्रश्न-
(a) आप अपने स्वास्थ्य को किस श्रेणी में रखते/रखती (कृपया किसी एक पर निशान लगाएं)
  (1) अच्छा (2) अच्छा (3) उत्तम (4) ठीक (5) खराब
(b) क्या आपको फिल्म 2 सप्ताह में किसी प्रकार की शारीरिक पीड़ा रही है? (कृपया किसी एक पर निशान लगाएं)
  (1) कभी नहीं (2) हलकी (3) मध्यम (4) अधिक (5) अत्यधिक
(c) क्या आपको ऐसी कोई स्वास्थ्य समस्या समस्या है जो आपको शारीरिक अभ्यास में झटका है?
  (1) है (2) नहीं
(d) आपने पूर्व रात्रि कितने घंटे सोया/तोया?
(e) आपने अपना पूर्व भोजन कब लिया?

........................................................................................................................................
........................................................................................................................................
# Appendix: 9

## POMS™ Brief Form

**Client ID:**

**Birth Date:**

**Today's Date:**

**Age:**

**Gender:**

### To the Administrator:

Place a checkmark in one box to specify the time period of interest.

### To the Respondent:

Below is a list of words that describe feelings that people have. Please read each word carefully. Then circle the number that best describes:

- how you have been feeling during the PAST WEEK, INCLUDING TODAY,
- how you feel RIGHT NOW,
- other.

If no box is marked, please follow the instructions for the first box.

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<th>Moderately</th>
<th>Quite a Bit</th>
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<td></td>
</tr>
<tr>
<td>Forgetful</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Vigorous</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Please ensure you have answered every item.

---

*POMS™ Brief Form by Douglas M. McNair, Ph.D., Maurice Lorr, Ph.D., Jw P. Bucceer, Ph.D., & Leo E. Droppleman, Ph.D.*

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**Appendices**
Appendix: 10

**SHORT Dispositional Flow Scale (S DFS)**

Please answer the following questions in relation to your experience in your chosen activity. These questions relate to the thoughts and feelings you may experience during participation in your activity. You may experience these characteristics some of the time, all of the time, or none of the time. There are no right or wrong answers. Think about how often you experience each characteristic during your activity, then circle the number that best matches your experience.

<table>
<thead>
<tr>
<th></th>
<th>Never</th>
<th>Rarely</th>
<th>Sometimes</th>
<th>Frequently</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 I feel I am competent enough to meet the demands of the situation</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2 I do things spontaneously and automatically without having to think</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3 I have a strong sense of what I want to do</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4 I have a good idea about how well I am doing while I am involved in the task/activity</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5 I am completely focused on the task at hand</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>6 I have a feeling of total control over what I am doing</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>7 I am not worried about what others may be thinking of me</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>8 The way time passes seems to be different from normal</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>9 The experience is extremely rewarding</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**SHORT Dispositional Flow Scale (S DFS), Copyright © 2002, 2009 by S.A. Jackson. All rights reserved. Published by Mind Garden, Inc. www.mindgarden.com**
**Appendix: 11**

*SHORT Flow State Scale (S FSS)*

Please answer the following questions in relation to your experience in the event or activity you have just completed. These questions relate to the thoughts and feelings you may have experienced while taking part. There are no right or wrong answers. Think about how you felt during the event/activity, then answer the questions using the rating scale below. For each question, circle the number that best matches your experience.

<table>
<thead>
<tr>
<th>During the event of <em>(name event)</em>:</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neither Agree nor Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 I felt I was competent enough to meet the demands of the situation</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2 I did things spontaneously and automatically without having to think</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3 I had a strong sense of what I wanted to do</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4 I had a good idea about how well I was doing while I was involved in the task/activity</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5 I was completely focused on the task at hand</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>6 I had a feeling of total control over what I was doing</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>7 I was not worried about what others may have been thinking of me</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>8 The way time passed seemed to be different from normal</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>9 I found the experience extremely rewarding</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

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Appendix: 12

TO WHOMSOEVER IT MAY CONCERN

This is to certify that Ms. Anupama Tyagi from Royal Melbourne Institute of Technology, Australia, will be visiting Patanjali Research Foundation (a unit of Patanjali Yogpeeth), India for her research project entitled "PSYCHO PHYSIOLOGICAL OUTCOMES OF SEATED AND SLEEP INTERVENTIONS" in the month of November and stay here for two months. Patanjali Research Foundation will be glad to help Ms. Anupama Tyagi in her research project by assisting her in data collection and she will be entitled to use the equipments available in Patanjali Research Foundation. Ms. Anupama Tyagi will bear expenses for her travel (international and local travel), boarding and lodging and for her meal during her visit.

Thanking you.

Sincerely

Shirley Telke, Ph.D. (Neurophysiology)
Director of Research
Patanjali Research Foundation
Haridwar, India

APPROVED:

Acharya Balkrishna
General Secretary
Patanjali Yogpeeth
Haridwar, India