Vital and Alive

an Exploration of Subjective Vitality and Its Physiological Correlates

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Abbreviations

AIC:	Akaike Information Criterion
AnG:	Angular Gyrus
ANOVA:	Analysis of Variance
ANCOVA:	Analysis of Covariance
ANS:	Autonomic Nervous System
ARAS:	Ascending Reticular Activation System
BDI:	Becks Depression Inventory
BSI:	Brief Symptom Inventory
CFA:	Confirmatory Factor Analysis
DSM-5:	Diagnostic and Statistical Manual of Mental Disorders 5
DMN:	Default Mode Network
ECG:	Electrocardiogramm
FC:	Functional Connectivity
Fl:	Flourishing
fNIRS:	Functional Near-infrared Spectroscopy
FusG:	Fusiform Gyrus
HF:	High-frequency Power
highFl:	High-flourishing
highSV:	High-vital
ICA:	Independent Component Analysis
IPL/AG:	Inferior Parietal Lobe/Angular Gyrus
LF:	Low-frequency Power
MLM$\mathcal{X}^2$:	Robust Maximum Likelihood Chi-square Statistic
mlVAR:	Multilevel Vector-auto-regressive Network Estimation
MPFC:	Medial Prefrontal Cortex
MTC:	Medial Temporal Lobe
MTG:	Middle Temporal Gyrus
NBS:	Network-based Statistics
OTP:	Open-thought Protocol
PANAS:	Positive and Negative Affect Scale
PCA:	Principal Component Analysis

PCC/Rsp:	Posterior Cingulate/Retrosplenial Cortex
PHQ-9:	Patient Health Questionnaire (Depression Module, 9 Items)
POMS:	Profile of Mood States
PSC:	Primary Somatosensory Cortex
SDNN:	Standard Deviation of Normal-to-Normal Intervals
SDT:	Self-determination Theory
SNS:	Synergetic Navigation System
SRMR:	Standardized Root Mean Square Residual
SWLS:	Satisfaction-with-life-scale
regFl:	Regular-flourishing
regSV:	Regular-vital
RMSEA:	Root Mean Square Error of Approximation
RMSSD:	Root Mean Square of Successive R-R Differences
RRS:	Ruminative Response Scale
RSFC:	Resting State Functional Connectivity
rTMS:	Repetitive Transcranial Magnetic Stimulation
SAC:	Somatosensory Association Cortex
SC:	Subcentral area/Secondary Somatosensory Cortex
SCL-90:	Symptom-Checklist-90
SEI:	Strength-exploring Interview
SF-36:	Short-Form Health Survey 36
SPcoherence:	Spline-interpolated Cardiac Coherence
SuG:	Supramarginal Gyrus
SV:	Subjective Vitality
SVS-G:	Subjective Vitality Scale in German
TCM:	Traditional Chinese Medicine
TLI:	Tucker-Lewis Index
V3:	Visual Area
VAS:	Visual Analog Scale
VIA:	Values-in-Action Inventory
vmPFC:	Ventro Medial Prefrontal Cortex
VLF:	Very Low-frequency Power

Abstract

The concept of vitality has attracted philosophers, scientists and medical practitioners for more than 2500 years. Today, an entire "vitality-industry", from diary supplements to self-help books, flourishes on people's quest for the "vital life". Research has shown that the subjective experience of energy and vitality is a powerful predictor of beneficial outcomes in individuals, organizations and society. However, studies that look at the link between physiological processes and the subjective experience of energy and vitality are completely lacking. The present dissertation aims to address this gap with an exploration of the link between the self-report measure of *Subjective Vitality* and two prominent present-day physiological correlates: *Resting state functional connectivity (RSFC)*, derived from human brain activity, and *heart rate variability (HRV)*. The correlates are examined in their relation to *trait*, *state* and *daily* levels of Subjective Vitality. Chapter 1 lays the foundation for all subsequent chapters by providing a German language validated self-report measure of vitality, the Subjective Vitality Scale in German. Chapter 2 explores patterns of RSFC and their relation to differences in trait Subjective Vitality. Changes in parameters of HRV and state Subjective Vitality during Qi Gong are explored in Chapter 3. Chapter 4 examines a specific HRV parameter as an indicator of vagal tone and its association with daily Subjective Vitality in patients during residential psychotherapy. Overall, the findings suggest specific physiological correlates for Subjective Vitality as a trait, state and on a daily basis. Subjective Vitality as a state shows associations with moderate peripheral-physiological activation and attainment of a state of cardiovascular coherence during Qi Gong. Daily levels of Subjective Vitality are associated with increased resting state vagal tone, psychological need fulfillment and habitual physical activity on the same day. Subjects high in trait Subjective Vitality display a distinctive pattern of RSFC in posterior and temporal parts of the cortex; areas, that are associated with body-related self-representation. All findings are discussed and integrated into a psychophysiological model of vitality. The present dissertation suggests Subjective Vitality as a marker of organismic well-being; covering a positive divergence in health, close to people's lay notion of vitality, and sensitive to somatic and psychological processes.

Kurzfassung

Seit mehr als 2500 Jahren beschäftigt das Konzept der Vitalität Philosophen, Mediziner und Wissenschaftler. Heutzutage erblüht eine ganze "Vitalitäts-Industrie", von Nahrungsergänzungsmitteln bis zu Selbsthilfebüchern, unter der Suche des Menschen nach dem "vitalen Leben". Forschungsergebnisse zeigen, dass das subjektive Erleben von Vitalität und Energie ein starker Prädiktor für positive Effekte in Individuen, Organisationen und auf gesellschaftlicher Ebene ist. Nicht vorhanden sind jedoch Studien zum Zusammenhang zwischen dem subjektiven Erleben von Vitalität und Energie, und physiologischen Prozessen. Ziel dieser Dissertation ist das Aufgreifen dieser Forschungslücke durch die Untersuchung des Zusammenhanges zwischen dem Selbstbericht-Maß *Subjektive Vitalität* und zweier viel-genutzter, physiologischer Korrelate der heutigen Forschung: *Funktionelle Konnektivität (RSFC)*, basierend auf hirnphysiologischer Ruheaktivität, und *Herzratenvariabilität (HRV)*. Die Korrelate werden in ihrer Verbindung zur *allgmeinen*, *momentanen* und *täglichen* Subjektiven Vitalität erforscht. Kapitel 1 bildet die Grundlage für alle nachfolgenden Kapitel durch die Validierung eines deutschsprachigen Selbstbericht-Fragebogens zur Messung von Vitalität, der Subjektiven Vitalitäts Skala in Deutsch. Kapitel 2 untersucht den Zusammenhang zwischen RSFC und Unterschieden von Subjektiver Vitalität als Trait. Veränderungen in HRV Parametern und der momentanen Subjektiven Vitalität während der Ausübung von Qi Gong werden in Kapitel 3 untersucht. Als Marker für vagalen Tonus untersucht Kapitel 4 einen spezifischen HRV Parameter und dessen Zusammenhang mit der täglichen Subjektiven Vitalität in Patienten während einer stationären Psychotherapie. Zusammenfassend sprechen die Ergebnisse für spezifische physiologische Korrelate von Subjektiver Vitalität als Trait, als momentanem Zustand und als tägliches Erleben. Subjektive Vitalität als Zustand zeigt einen Zusammenhang mit moderater peripher-physiologischer Aktivierung und dem Erreichen eines Zustandes von kardiovaskulärer Kohärenz während Qi Gong. Tägliche Subjektive Vitalität zeigt einen Zusammenhang mit erhöhtem vagalen Ruhetonus, Erfüllung psychologischer Grundbedürfnisse und gewohnheitsmäßiger körperlicher Aktivität am gleichen Tag. Personen mit einem hohen Maß an Subjektiver Vitalität als Trait zeigen ein spezifisches Muster funktioneller Konnektivität in posterioren und temporalen Bereichen des Kortex; Areale welche mit körperbezogener Selbstrepräsentation assoziiert sind. Alle gefundenen

Ergebnisse werden diskutiert und in einem psychophysiologischen Modell von Vitalität zusammengeführt. Die vorliegende Dissertation bewertet Subjektive Vitalität als Marker für organismisches Wohlbefinden; fähig positive Abweichungen in der Ausprägung von Gesundheit zu erfassen, nah an Vitalitätskonzepten der Allgemeinbevölkerung und sensitiv gegenüber somatischen, wie auch psychologischen Prozessen.

To the people who inspired this work...

Preface

A vital person: is there such a thing?

Eric is 10 years old. He is in the fourth grade. Sitting still in class is very hard for him. As soon as he gets home, he is out of the house on the soccer field. He spends most of his time outdoors, playing with his friends, often until it gets dark. During the summer he loves to swim in the river and build tree houses. His favorite days in school are the ones with PE. After 2 hours of swimming the teacher says Eric has a balanced energy.

Niobe is a 28 years old student of international economics. She's short, cheerful and full of energy. Following high-school she spent time in Uruguay, Portugal and South Africa as a student and volunteer. She plays violin in the local student orchestra and does gymnastics three times a week. On the side, she teaches econometrics to first-year students and helps at the local music festival. Her friends often wonder where all this energy in Niobe is coming from.

Dylan is 42 years old and an entrepreneur. He and his wife have three kids. After a career as a professional football player he started his own business. The company now has 250 employees working in five different countries. Its head quarter includes a large open kitchen, a soccer field and a gym which Dylan and his employees use daily. His life is family-centric: they love to go on extended holidays, traveling to a different continent each time. He enjoys taking long walks in the forest to solve business problems. Friends and employees describe his energy as very contagious.

Marie is 82 years old. She is a well-dressed lady with white hair and a resolute attitude. She has a husband, three grown-up children and six grandchildren. Her days usually start with half an hour of stretching and yoga. She used to do ballet dancing and her grandchildren still love it when she dances with them in the kitchen. Her days are filled with activities – shopping, walks to the city center, meeting friends. She also works as a volunteer in an elderly nursing home where she's known by all staff members as the lady "who is going to survive them all".

When do you feel vital and alive?

"During a fun night with friends: we meet in the evening or something happens spontaneously. I sense joy, a little tingling in my body and I would think how good it is to be here..."

"During a ski-run, I sense the ground under my feet, how it passes by, I sense the cold in my face; but I am warmly wrapped in my clothes, effort I can control."

"During a hiking vacation in Norway. In the morning, I came out of our tent and had an amazing view. The vastness took my breath away, all around me was just nature and I felt filled with energy."

"After my first final state examination. The aliveness came because of such a big relief. I just felt free."

"I feel especially alive when I dance. I dance Salsa. If I dance with a guy who is much more advanced, and he helps me to dance at his level, doing steps I've never learned before, I feel super alive. Because I get the feeling of outgrowing myself."

"Sensing the 640 Newtonmeter power acceleration during the acceleration of my BMW X3."

"Concert of my favorite band. Loud music that I like. Nice people and atmosphere. Great sound of instruments, recognizing my favorite songs and singing along with my favorite songs."

"Working in the garden, concentrating on creating, fresh air, visible results, a feeling of freedom and self-efficacy, joy from the beauty of things."

"While traveling. The moments, when we were about to leave for a new city or a new place."

"While listening to somebody who talks "real" about themselves and shows emotion; sometimes during meditation, when the attention is focused on the body. It seems to be always, when my attention is not on my thoughts or taking in external information, where more senses are involved, where it is about contact."

"Riding a borrowed motor cycle through the rice mountains of Yunan province in China, the sun is shining, I can feel the cool air on my back, my body relaxed, joy, I think 'this is freedom', 'In this moment I feel alive.'"

General Introduction

Vitality – an Everyday Phenomenon

A person's vitality is one of their most salient and yet, unseizable features. People like Dylan or Niobe display a quality which friends and strangers describe as "high levels of energy or vitality". Similarly, most of us can recall situations such as "this fun night with friends" or "the motorcycle ride" that made us feel more "vital and alive". However, what is this quality of energy or vitality? Is there a way to quantify the difference between Niobe and ordinary people's level of vitality? What does science have to say about this everyday phenomenon of vitality?

In search of an answer one can go back several hundred years. The topic of vitality is an old one, likely as old as mankind's search for what distinguishes the animate from the inanimate (G. Brown, 1999). A full consideration of the corresponding literature is therefore beyond the scope of this work. The approach in this dissertation is bio-medically empirical, as vitality has also been studied in other areas using different methodological approaches. Among these are philosophy (Bergson, 2013), religious traditions (Cleary, 1991) and developmental studies (Stern, 2010). On a general level, the work at hand focuses on three questions:

1. How can the everyday phenomenon of vitality be measured?
2. What is the relationship between the subjective experience of energy and vitality and objective physiological correlates of vitality?
3. What is the relevance of a concept such as vitality in the present landscape of health and science?

Prior to turning to each of these questions in chapters 1-4, I will further specify them in the following introduction. I will do so by highlighting some historic approaches towards the conceptualization and measurement of vitality and review recent evidence on the relevance of the subjective experience of energy and vitality as a marker of health and well-being. I will give an overview of the scientific context of this dissertation and how the present work intends to contribute to it. Furthermore, I will introduce the reader to the concept of *Subjective Vitality* and two physiological indicators used as sources for the physiological correlates in the following chapters. The introduction will conclude with the aim and outline of each chapter, and the applied study design to answer the posed questions.

A Brief History of the Vitality Concept

Early Concepts

Among the first, whose thoughts' on vitality are available to the modern scholar are the Ancient Greeks (G. Brown, 1999). Between 800 BCE and 200 CE major Greek thinkers theorized on *pneuma* as a form of wind, vital breath or heat, central to the processes of life (Lloyd, 2007). Over time, the exact meaning of the term varied considerably between authors but also within the works of a single author. Aristotele's understanding of a "vital heat" differed from the Stoic's idea of an "active principle" and by the time Galen proposed "vital pneuma" to be the cause of activity in the heart and the brain, a range of interpretations and concepts coexisted, often contradicting each other (Lloyd, 2007).

Around the same time (ca. 500 BCE), the core scripture of Traditional Chinese Medicine, the Huangdi Neijing, conceptualized *Qi* as a vital force or energy, tantamount to the source of life, creativity, right action, and harmony (Maoshing, 1995). Qi could be inherited from the parents, nurtured by the right lifestyle and mobilized with the right treatment and exercise. To the present day, it is a key concept in traditional Chinese medicine (Kaptchuk, 2014) and part of the daily life vocabulary in Chinese-speaking countries.

Concepts similar to the Greek pneuma or the Chinese Qi can be found in a range of traditions (G. Brown, 1999; Ryan & Frederick, 1997). All these approaches share the idea of an underlying vital energy driving the processes of life. This vital energy can not be observed directly, but is inferred via indirect observation of phenomena such as intentional motion, change in appearance or vital signs (G. Brown, 1999). As such, the concept has often been used to link observable objective and hidden subjective aspects of natural phenomena (G. Brown, 1999; Lloyd, 2007). In a way, this distinction foreshadows the central question of the present work: How are objective physiological measures linked to the subjective experience of energy and vitality?

Psychological and Physiological Aspects

The distinction between objective physiological and subjective psychological aspects is also prevalent in modern Western thought (Herrmann-Lingen, 2017). Regarding vitality, psychodynamic theory is a prominent modern example of a framework which focuses on psychological factors. Sigmund Freud (Freud, 1975), in the development of psycho-analysis, used the concept of *libido*, a presumed driving force, which he assumed to be central to all mental processes. As a trained physician and neurologist he considered the force to be linked to human brain activity. However, no evidence exists that he ever investigated this assumption empirically (Freud, 1975). Subsequent psychodynamic theorists all converged on the idea that psychological conflict and its resolution are connected to the availability of energy or vitality to the self, but no advancements were made with regard to finding a physiological correlate of libido (Ryan & Bernstein, 2004). Most vividly the discourse on energy and vitality has survived in Freud's descendants of body oriented psychotherapy (Marlock & Weiss, 2006). Here, prominent approaches such as bio-energetics link a person's vitality to the status of muscular tension in the human body (Lowen, 1979; Reich, 1969).

Within the physiological realm, a 20^{th} century perspective on vitality was put forward by Hans Selye (Selye, 1978). The father of the stress concept used the term vitality with regard to a body inherent energy, utilized to adapt to external demands. This *adaptive energy* he assumed to be a basic feature of life itself (Selye, 1978) and a decisive determinant of the human lifespan. However, his concept of adaptive energy was also derived not from direct observation but inferred from physiological changes he found in animal studies and his patients after periods of increased stress (Selye, 1936).

The Area of Vitalism

Apart from applied research in medicine and psychology, physicists, chemists and biologists, were concerned with finding a "vital force underlying all living phenomena" (Mayer, 2010). Until the 19^{th} and even into the 20^{th} century, *vitalism* was a widespread assumption among scientists and the public. However, over the course of the 19^{th} century high-resolution models of biochemical processes and mechanistic explanations eventually led to the decline of vitalism (G. Brown, 1999; Westfall, 1977). 120 years after Buchner (1897) demonstrated the "vital process" of fermentation outside living cells, vitalism and with it the concept of vitality vanished from scientific discourse as its power to explain empirical phenomena seemed expended (Mayer, 2010).

This brief review of history shows how over the last 2500 years multiple approaches have been taken towards the conceptualization and measurement of vitality. The section highlights the concept's relevance within frameworks of philosophy, medicine and general science. Furthermore, it shows the difficulty to measure vitality and disentangle subjective from objective physiological aspects.

The Subjective Experience of Energy and Vitality

Despite the concept's disappearance from the scientific discourse of chemists and physicists, vitality continues to be present in the daily life language of lay people and as a multi-billion dollar business in the area of health and self-help (LaRosa, 2018). Magazines, books and an entire "vitality-industry" flourish on people's interest in "a life filled with energy and vitality" (e.g., www.vital.de). From the public interest point of view, the concept has lost none of its relevance 2500 years after the ancient Greek's concern with the topic. In fact, compared to vitality as a general concept, the *subjective experience of energy and vitality* has inspired accumulating research showing it as a promising correlate of beneficial outcomes in individuals, organizations and society.

T. Schwartz and McCarthy (2007) outline that in the business world "personal energy" is one of the most critical variables to be managed for personal success. The "subjective sense of energy" is positively associated with self-made economic success (Hahn et al., 2012) and athletes with higher levels of "vigor" perform better (Beedie et al., 2000). "Lack of energy" and "fatigue" are core symptoms of general illness (Watanabe et al., 2008) and one of the most disabling diseases worldwide: depression (Fried et al., 2016; James et al., 2018). In contrast, "self-reported vitality" is associated with better physical health (Kubzansky & Thurston, 2007) and healthy behavior such as tobacco abstinence (Niemiec et al., 2010). "Vital people" engage more in volunteering work for society, create fewer costs in the healthcare system and have higher rates of attendance at work (van Steenbergen et al., 2015). When asked people rate the personality trait of "zest" as one of the central contributors to a happy life (Peterson et al., 2007).

The results of these studies indicate that energy, vigor, vitality or zest, if subsumed under the subjective experience of energy and vitality, are meaningful correlates of health and performance in individuals, organizations and society. However, as this section shows the subjective experience of energy and vitality has not been researched under a shared conceptualization and framework. A potential reason lies in three blind-spots of the scientific context linked to the concept of vitality that will be described in the following section.

Scientific Context

Positive Psychology

In the last sixty years, psychology has made great progress in the understanding and treatment of mental health disorders (Seligman & Csikszentmihalyi, 2000). In comparison, research on the aspects of health that goes "beyond the absence of disease and infirmity" (World Health Organization, 1948, p. 1) has been rather scarce. Building on the work of pioneers such as Maslow (1977), Frankl (1946), Antonovsky (1987) and others, the area of positive psychology has complemented the clinical perspective for the last two decades, by emphasizing an empirical lens on the things that "make life worth living" (Seligman & Csikszentmihalyi, 2000, p. 5). Since then, a growing number of studies have investigated positive experiences, positive individual traits and institutions that allow people to flourish (Seligman, 2012). As a result, the concept of vitality has regained attention and raised questions regarding its physiological underpinnings, causes and consequences, potential applications and development over the course of a lifetime (Peterson & Seligman, 2004). However, despite a growing number of studies, the concept has received only limited attention in central theoretical frameworks of health and positive psychology. It is not part of a common theory of well-being (Seligman, 2018). One of the most widely used measures of general health, the SF-36, includes items to measure vitality without theoretical considerations but due to an "impressive record of empirical validity" (Ware & Sherbourne, 1992, p. 477). Hence, one goal of this dissertation is to further examine vitality as a marker of positive health and its potential to capture aspects beyond the absence of disease and infirmity.

Physiology and the Role of the Body

A discourse on vitality, as outlined in the section on the history of the concept, inevitably leads to the question of the relationship between the body and the mind (G. Brown, 1999; Lloyd, 2007). One reason for the restrained interest in vitality may be the concept's characteristic as a hybrid at the intersection of physiological and psychological processes. Empirical psychology has seen ups and downs regarding the relation between psychological processes and the body (Glenberg et al., 2013). Over the last 25 years, however, the role of the body has received increasing attention from practitioners (Payne et al., 2015; Tschacher & Pfammatter, 2016; Van der Kolk, 2015) and researchers (Glenberg et al., 2013; Meier et al., 2012), especially regarding higher order processes in decision making and the notion of self (Blanke, 2012; Damasio, 1996; Damasio et al., 2000). Furthermore, improved technology and methodological advancements have enabled an increasing linkage between physiological and psychological phenomena (Kemp et al., 2017; Mather & Thayer, 2018; Tschacher et al., 2017). This development, however, has only started to reach the above mentioned field of positive psychology. Despite the call for an initiative on positive health (Seligman, 2008) and promising first studies (Greene & Seligman, 2016; Kok et al., 2013; Shiota et al., 2011), research on the interactions of physiological and psychological processes in well-being research is scarce (Esch & Hirschhausen, 2014). Considering the current state, research on the relation between the subjective experience of energy and vitality and its physiological correlates holds promise for the extension of positive psychology into a positive psychophysiology. Hence, a second aim of this dissertation is to contribute to the exploration of the psychophysiological dynamics underlying human well-being using the example of vitality.

Lay Concepts and the Complexity of Science

A third development important to this dissertation is the link between the everyday phenomenon of vitality and the increasingly complex physiological processes now studied by scientists to describe these phenomena (D. S. Bassett & Sporns, 2017; Obermeyer & Emanuel, 2016). As demonstrated above, people seem to have an intuitive understanding of vitality; their own and that of others. Despite their "lack of accuracy" and "scientific rigor", lay theories in general have proven to be powerful predictors of attitudes, intentions and behavior (Molden & Dweck, 2006; Zedelius et al., 2017). So what about people's lay theories on vitality? How good is a person's subjective experience of energy and vitality as a predictor of general health?

Science has now more objective data available on the multiple layers of human physiology than a human observer can possibly process (Obermeyer & Emanuel, 2016). At the same time, people are capable of reporting a subjective experience of energy and vitality which potentially summarizes all this information into a single rating of *organismic well-being* (Ryan & Frederick, 1997). The underlying question is: What are the advantages and disadvantages to use this organismic statement of well-being? Is it actually organismic and how does such a single rating relate to the complex interacting layers of human physiology? Hence, in examining the relation between the subjective experience of energy and vitality and objective physiological correlates, the present work wants to evaluate people's lay theories on vitality regarding their potential as a marker of organismic well-being.

The previous sections describe three blind-spots in the scientific landscape linked to the concept of vitality and how the present research intends to contribute to the exploration of these blind-spots. So far, the concept of vitality has been described in general terms. The following section introduces a specific concept to capture the subjective experience of energy and vitality as a foundation for the subsequent studies.

Subjective Vitality

Subjective Vitality - Definition

The key concept of this dissertation with regard to the phenomenological experience of vitality is *Subjective Vitality (SV)* understood as the "conscious experience of possessing energy and aliveness" (Ryan & Frederick, 1997, p. 530). Subjective Vitality has also been described as

- "a positive feeling of aliveness and having energy available to the self" (Ryan & Bernstein, 2004, p. 276)
- "having physical and mental energy" (Ryan & Deci, 2008, p. 703)
- a dynamic aspect of organismic well-being related to psychological and somatic factors (Ryan & Bernstein, 2004)

Conceptually, the construct of Subjective Vitality shows an overlap with feelings of vigor (Lorr & McNair, 1971), activated positive affect (Watson et al., 1988) and calm energy (R. Thayer, 1996), all of which entail positively toned energized states. Conceptual and empirical distinctions can be drawn from states of mere activation and arousal (Ryan & Bernstein, 2004) and non-activated positive states such as happiness, satisfaction, and contentment (Lorr & McNair, 1971; Nix et al., 1999). As a trait, Subjective Vitality relates to facets of positive affect and activity as aspects of Extraversion (Ryan & Frederick, 1997) and a temperamental disposition for activity and positive affect (Rothbart, 2007; Thomas et al., 1970). A major reason to use Subjective Vitality in the exploration of physiological correlates instead of other aforementioned concepts is its theoretical background.

Subjective Vitality - Theoretical Background

The concept of Subjective Vitality emerged from a large body of research on motivation under the label of self-determination theory (SDT; Deci & Ryan, 1985a; Ryan & Deci, 2000). SDT is a motivational theory concerned with the "what" and "why" of human behavior (Deci & Ryan, 2000). Within the framework of SDT, Subjective Vitality is seen as a consequential and conscious indicator of intrinsic motivational processes (Frederick & Ryan, 1993; Ryan & Deci, 2008). The authors assume that intrinsic motivation, in contrast to extrinsic motivation, leads to longer lasting behavioral engagement, health and well-being as it corresponds with a human being's natural tendency to be active, exploring and thriving towards psychological integration. These processes can only be maintained as long as a person is provided with sufficient energy or "nutriment".

According to Deci and Ryan (2000), three innate psychological needs specify the conditions for this ongoing energizing in human behavior. The need for *competence*, understood as feeling effective in the interaction with one's own environment. The need for *autonomy*, understood as feeling volitional rather than controlled by external factors. Thirdly, the need for *relatedness* as feeling significant and connected to others. Activities that satisfy those basic psychological needs maintain or enhance Subjective Vitality (Gunnell et al., 2013; Reis et al., 2000; Ryan, Bernstein, et al., 2010; Ryan & Frederick, 1997; Sheldon et al., 1996). Activities and events that thwart these needs drain Subjective Vitality (Bartholomew et al., 2011; Neubauer & Voss, 2016; Ryan & Deci, 2008). All studies measured Subjective Vitality via means of self-report and assessed it using the time reference of a trait, state or day (Reis et al., 2000; Ryan, Bernstein, et al., 2010; Ryan & Frederick, 1997).

Measuring Subjective Vitality – the Subjective Vitality Scale

The Subjective Vitality Scale was derived by Ryan and Frederick (1997) from a larger sample of items "concerning perceptions of having energy, zeal, interests, purposes in life, and feelings of aliveness" (Ryan & Frederick, 1997, p. 539). Factor analysis revealed a single factor exclusively associated with feelings of energy and aliveness. The resulting seven items were "an adequate definition of a phenomenological sense of aliveness and energy, and thus were summed to create a variable labeled Subjective Vitality" (Ryan & Frederick, 1997, p. 540). The items of the original scale are:

1. I feel alive and vital
2. I don't feel very energetic (reversed)
3. Sometimes I feel so alive I just want to burst
4. I have energy and spirit
5. I look forward to each new day
6. I nearly always feel alert and awake
7. I feel energized

Chapter 1 describes in detail how further studies modified the scale based on psychometric analyses (Bostic et al., 2000; Kawabata et al., 2017). The original authors used a 7-point Likert-scale format ranging from 1 (*not at all true*) to 7 (*very true*) to assess current state (How do these statements apply to you and your life at the present time?) and trait Subjective Vitality (How do these statements apply to your life in general?). Later studies adapted the state scale to measure Subjective Vitality on a daily basis (Reis et al., 2000).

Building on these studies, each reference of time for Subjective Vitality (trait, state, day) is used as a phenomenological correlate of vitality in chapters 2-4. Prior to an introduction to the physiology of Subjective Vitality the specific role of the *self* in Subjective Vitality, important to the selection process of physiological correlates, will be outlined in the following section.

Subjective Vitality – the Role of the Self

The self in SDT

Its theoretical background in SDT (Deci & Ryan, 1985a; Ryan & Deci, 2000) distinguishes Subjective Vitality from other conceptualizations of vitality such as mood (Lorr & McNair, 1971; R. Thayer, 1978; Watson et al., 1988; Wilhelm & Schoebi, 2007), general population health (Ware & Sherbourne, 1992) and emotional/mental vitality (Kubzansky & Thurston, 2007; Penninx et al., 1998; Richman et al., 2009).

A central aspect of the difference is the explicit role of the self in the conceptualization of Subjective Vitality. Ryan and Frederick (1997) define Subjective Vitality as "energy available to the self" (Ryan & Frederick, 1997, p. 529) implying the presence of a certain amount of energy, but also an instance of self experiencing itself in relation to that energy. SDT defines the self in an abstract way: as a result and current state of an ongoing process which connects internal motivations and environmental influences (Deci & Ryan, 1991). According to SDT, the self is marked by a constant strive for autonomy and integration via assimilatory and regulatory functions (Ryan et al., 1997). With regard to Subjective Vitality, the concept of self allows a connect to other layers of personality, also on the physiological level (Kuhl, 2009). It is emphasized here, because more specific physiological correlates can be considered linked to the self in Subjective Vitality, than for the outlined measures of mood or health.

The self and measures of conceptual proximity

On a conceptual level, the criterion of self allows the authors to contrast Subjective Vitality with "feelings of arousal or energy, that are not typically associated with personal control, such as jitteriness, anxiety, or pressure" (Ryan & Frederick, 1997, p. 531). Furthermore, the state of the self differentiates Subjective Vitality from the concept of flow which includes the loss of the conscious experience of self, (Czikszentmihalyi, 1990) in contrast to the conscious experience of self in Subjective Vitality.

In addition, the type of control over energy experienced by the self, distinguishes Subjective Vitality from the concept of ego-depletion (Baumeister et al., 1998), which is also concerned with energy available to the self (Ryan & Deci, 2008). However, ego-depletion is based on "controlled forms of regulation, whereas autonomous self-regulation maintains or enhances energy or vitality" (Ryan & Deci, 2008, p. 711).

Overall, this section highlights how the use of a concept of self in Subjective Vitality offers additional options in the selection of physiological correlates and a distinction to measures of conceptual proximity. Based on the discussed conceptualization, two aspects in Subjective Vitality are considered in the selection of physiological correlates: the aspect amount of energy (*energy*) and the aspect sense of availability to the self (*sense of self-availability*). Both aspects serve as starting points in the selection of specific physiological correlates for Subjective Vitality, described in the following sections.

Subjective Vitality and Physiology

At the outset of this dissertation, a single study existed on the physiological correlates of Subjective Vitality (Barrett et al., 2004). Barrett et al. (2004) studied the influence of repetitive transcranial magnetic stimulation (rTMS) on affect, while measuring Subjective Vitality as an additional dependent variable. The authors found a decrease in Subjective Vitality following 10-Hz rTMS over the left mid-dorsolateral frontal cortex accompanied by a reduction in aggregated general affect as well as increased monotony of speech as a behavioral correlate. In contrast, explicit measures of positive or negative affect did not show a significant change. The result highlights both, potential physiological specificities of Subjective Vitality and a distinction to measures of affect. Despite these findings, physiological correlates of Subjective Vitality have not been assessed in any further studies.

The Present Approach to Physiological Correlates

Due to the scarcity of research on the physiology of Subjective Vitality, the present selection of physiological correlates is exploratory in nature. It relies on findings for conceptually related constructs such as measures of well-being and physiological correlates identified as general indicators of health. More specifically, physiological correlates are selected based on prior evidence of a link to the sub-components highlighted in the definition of Subjective Vitality: energy and a sense of self-availability (Ryan & Deci, 2008; Ryan & Frederick, 1997). The sub-component of energy features conceptual proximity to the construct of arousal/activation (R. Thayer, 1978), which is widely assessed in emotion and mood research using peripheral-physiological correlates (Cacioppo et al., 2000; R. Thayer, 1970). Research regarding the sense of self-availability in contrast, implies involvement of higher order processes, which have been researched predominantly using the physiological correlate of brain activity (Damasio, 1999; Northoff et al., 2006). Hence, a peripheral-physiological, as well as a correlate of brain-activity, are used as correlates to allow for an exploration of both sub-components in Subjective Vitality. An introduction to each specific physiological correlate is given in the following section.

Physiological Correlates Used in This Dissertation

The two physiological correlates used in this dissertation are *resting state functional connectivity* (RSFC), derived from human brain activity (Friston et al., 1993; Raichle et al., 2001), and *heart rate variability* (HRV; Malik, 1996). Both correlates are applied widely in research on general health, performance and well-being (Berntson et al., 1997; Kemp et al., 2017; Laborde et al., 2017; Raichle, 2015; Shaffer & Ginsberg, 2017; Shaffer et al., 2014; Spetsieris et al., 2015; L. Wang et al., 2012). Furthermore, both correlates have demonstrated a linkage to measures of arousal/activation (Bonnet & Arand, 1997; Fan et al., 2012) implying a potential relationship with Subjective Vitality's sub-component of energy. The correlates have also been linked to the subjective experience of self or self-regulation (Northoff et al., 2006; Raichle, 2015; Segerstrom & Nes, 2007) implying a potential relationship with the sub-component sense of self-availability. HRV has even been proposed as a potential marker of the interaction between peripheral-physiological arousal/activation and higher-level self-regulative capacity (Mather & Thayer, 2018; Shaffer & Ginsberg, 2017; J. Thayer & Brosschot, 2005), which makes it a particularly interesting physiological correlate of Subjective Vitality. The following sections introduce RSFC and HRV in detail and outline theoretical ties to the concept of Subjective Vitality.

Resting State Functional Connectivity

Resting state brain activity and functional connectivity

People high in trait Subjective Vitality agree to statements such as "In general, I feel very vital and alive". Hence, these people report Subjective Vitality not in response to a specific situation but as a "general mode of being". One of today's most specific physiological correlates regarding this general mode of being is brain activity at rest. To explore a physiological correlate of trait Subjective Vitality we therefore assess RSFC, a correlate based on resting state brain activity. As the name suggests, resting state refers to the activity of the brain in the absence of any intentional task (Raichle et al., 2001). Observing brain activity during such a condition has a long tradition in neuroscience (Berger, 1929). It is commonly used in the study of emotional traits (Alessandri et al., 2015; Volkow et al., 2011; Z. Wang et al., 2013), personality (Kong, Liu, et al., 2015), conditions of health and illness (Mohan et al., 2016; Mulders et al., 2015) and the sense of self (Davey et al., 2016; Northoff et al., 2006; Raichle et al., 2001). Over the last 20 years, technological and methodological developments have allowed resting state brain activity to be studied in more and more detail on a temporal as well as a spatial level (Northoff et al., 2019). A central measure in this process has been functional connectivity (FC), the specific correlate used in this dissertation. FC is defined by the change in temporal correlations of spontaneous brain activity in spatially remote areas in the resting brain (Friston et al., 1993). The application of FC has contributed largely to a view of brain activity in terms of networks (Greicius et al., 2003; Yeo et al., 2011). From a network perspective, traits and states of a person are linked to specific patterns of co-activation within and between their neuronal networks.

RSFC and trait Subjective Vitality

Regarding trait Subjective Vitality, a network with likely relevance is the default mode network (DMN; Buckner et al., 2008; Raichle et al., 2001). The DMN is defined by its activity in the absence of any intentional task (Raichle et al., 2001) and therefore a promising starting point for studying differences in the general mode of being. Furthermore, the DMN shows aberrant patterns of activation in depression (Mulders et al., 2015; D. Rosenbaum et al., 2016), a condition, which in many aspects mirrors the phenomenological opposite of Subjective Vitality (Huppert & So, 2013). Positive emotional traits and happiness have also been linked to specific patterns of DMN activation (Luo et al., 2015; Luo et al., 2017; Volkow et al., 2011). One proposed reason for the importance of the DMN regarding well-being, is its role as a connecting hub between (sub-) cortical pleasure spots and cortical areas linked to higher mental processes (Kringelbach & Berridge, 2017). In fact, higher mental processes such as self-referential thought (e.g., rumination, day dreaming etc.), are a central hypothesis in explaining degrees of happiness linked to varying patterns of RSFC in the DMN (Luo et al., 2015; D. Rosenbaum et al., 2017). Hence, structures of the DMN are a central focus in the exploration of RSFC as a correlate of trait Subjective Vitality.

Another way how differences in RSFC around the DMN are potentially linked to differences in trait Subjective Vitality is via distinct coupling of the DMN with other neuronal networks. For instance, research has shown that differences in coupling between the DMN and areas associated with sensorimotor activity are indicative of lasting periods of low arousal (e.g., depression) vs. periods of high arousal (e.g., mania) (Martino et al., 2016). Since arousal/activation is close to the energy sub-component of Subjective Vitality, differences in FC coupling between the DMN and related brain areas are a second focus in the study of RSFC as a physiological correlate of trait Subjective Vitality. The associations between RSFC in the DMN, related brain areas, self-referential thought and trait Subjective Vitality are explored in chapter 2.

Heart Rate Variability

Theoretical background

The fluctuations in interval length between single human heart beats are the basis for the calculation of parameters under the common label of HRV (Malik, 1996; Shaffer & Ginsberg, 2017). HRV has originally been highlighted as a promising predictor of cardiovascular risk and general health impairment (Malik, 1996). Over the last decades, the measure has inspired studies on a range of other topics such as cognitive and physical performance, self-regulation, mood and emotions, health and social cognition (Kemp et al., 2017; McCraty & Zayas, 2014; Shaffer et al., 2014). Generally speaking, higher levels of HRV are indicative of more positive emotions

(Duarte & Pinto-Gouveia, 2017; Sloan et al., 2016), better ability to self-regulate (Kemp et al., 2017; McCraty & Zayas, 2014; Segerstrom & Nes, 2007), increased psychophysiological health (Kemp et al., 2017; J. Thayer et al., 2012) and fewer symptoms of depression (Kemp et al., 2010). Based on these findings, a positive association between HRV and Subjective Vitality can be expected.

HRV and Subjective Vitality

A specific reason for the selection of HRV as a physiological correlate of Subjective Vitality is the fact that activity of the autonomic nervous system (ANS), in particular parasympathetic activity, can be inferred from its assessment (Shaffer et al., 2014). As such, HRV can serve as a correlate of peripheral-physiological arousal/activation in the ANS linked to the energy sub-component of Subjective Vitality.

Besides being a correlate of peripheral-physiological arousal/activation, the measure of HRV has been used as an index of self-regulatory strength (Segerstrom & Nes, 2007). Prominent physiological models suggest that self-regulation happens via neural connections between the prefrontal cortex and the two branches of the ANS (J. Thayer et al., 2012; J. Thayer & Lane, 2000). As a consequence, HRV may not just be linked to the sub-component of energy, but also to the sub-component sense of self-availability indicating prefrontal regulative capacity over the ANS.

Taken together, a conceptual proximity exists between Subjective Vitality and HRV. Both measures indicate a person's capacity to meet external and internal demands. Subjective Vitality on the phenomenological level, HRV on the physiological level. Subjective Vitality expresses the amount and felt capacity to influence one's life circumstances (energy available to the self). HRV indicates the ANS' current state of mobilizing energy (sympathetic nervous system), restoring energy (parasympathetic nervous system) as well as the capacity to regulate energy (prefrontal modulation).

In order to interpret HRV correctly, the measurement set-up as well as the exact parameter selection are crucial factors to consider (Laborde et al., 2017; Shaffer & Ginsberg, 2017). Chapter 3 examines HRV pre-post and in response to an exercise. Chapter 4 examines HRV under daily short-term (5min) resting state conditions (Shaffer & Ginsberg, 2017). Both set-ups will be described shortly in the following sections.

Acute changes in HRV parameters

To explore HRV as a physiological correlate of state Subjective Vitality, changes in a range of standard parameters (Laborde et al., 2017; Tiller et al., 1996) are examined during a specific exercise. The exercise (Qi Gong) explicitly assumes an increase of vitality in the practitioner via means of psychophysiological regulation (Chow et al., 2012). However, no empirical evidence exists on this mechanism. To allow for a broad exploration of potential linkages to changes in state Subjective Vitality, a range of different HRV parameters (SDNN, RMSSD, HFpower, VLFpower, HR, cardiac coherence, SPcoherence) are examined. The details of each parameter are described in chapter 3. Because acute modulating effects of Qi Gong on the ANS and subjective state can be expected (Chen & Liu, 2010), HRV parameters are examined during a resting state prior and after the exercise as well as in direct response to the exercise. The study of acute changes in HRV parameters and their association with changes in state Subjective Vitality during Qi Gong are explored in chapter 3.

Daily changes in resting state vagal tone

As a correlate of daily Subjective Vitality, chapter 4 focuses on one specific HRV parameter during a short-term (5min) resting state condition. HFpower (HFm^2), calculated over a 5-min resting state, is a standard parameter used to track developments in repeated-measure field settings of health and performance (Koenig et al., 2016; Kok et al., 2013; Plews et al., 2013). A particular reason for the use of HFpower is its exclusive interpretation as a marker of vagal tone (Laborde et al., 2017). Vagal tone refers to the activity of the vagus nerve, which is considered the main nerve of the parasympathetic nervous system (Brodal, 2004). Following Laborde et al. (2017), vagal tone will be used as a term for parasympathetic nervous system activity in the following chapters. *Resting state vagal tone* as assessed in chapter 4 can be understood as baseline activity of the parasympathetic nervous system. Higher resting state vagal tone is associated with a range of positive outcomes such as positive emotional states, social connectedness, flexible cognitive control and increased capacity to regulate and to transition into a regenerative state (Kemp et al., 2017; Laborde et al., 2017; Shaffer et al., 2014). Furthermore, daily experiences influence resting state vagal tone (Kemp et al., 2017) as they influence daily levels of Subjective Vitality (Reis et al., 2000; Ryan, Bernstein, et al., 2010; Sheldon et al., 1996). Resting state vagal tone is reduced in patients with depression (Kemp et al., 2010; Koenig et al., 2016), a condition in many facets opposite to Subjective Vitality (Huppert & So, 2013). The clear interpretation and wide use as a short-term resting state measure of psychological and physical health (Kemp et al., 2017; Kemp & Quintana, 2013) qualified resting state vagal tone, indexed via HFpower, as correlate for daily Subjective Vitality in chapter 4.

Aims and Outline

The overall goal of this dissertation is to explore the everyday phenomenon of vitality with a specific focus on the physiological correlates of the subjective experience of energy and vitality. Starting with the translation and validation of a prominent instrument to measure vitality via self-report (Chapter 1), the following three chapters focus on physiological correlates of Subjective Vitality as a trait (Chapter 2), state (Chapter 3) and during the day (Chapter 4). The term Subjective Vitality is used throughout all four chapters and refers to the time reference of the respective chapter if not stated otherwise. On a general level, the dissertation is guided by questions for Subjective Vitality's potential to capture aspects of health beyond the absence of disease, its role at the intersection of psychological and physiological processes and the concept's closeness to lay theories of vitality. The aim and outline of each chapter will be described in detail in the following paragraphs.

Chapter 1

As a foundation for the subsequent studies, Chapter 1 describes the translation and validation of a prominent self-report instrument to measure vitality – the Subjective Vitality scale (Ryan & Frederick, 1997). To establish the measure for German-speaking populations, psychometric characteristics and associations between trait Subjective Vitality, relevant clinical phenomena (depression, anxiety, somatic symptoms, fatigue), related constructs of well-being (vigor, life satisfaction) and SDT based assumptions (basic psychological need satisfaction for competence, relatedness, autonomy, hours spend on work or leisure activities per week) are examined in a large online sample (N = 632). The second study in Chapter 1 validates a state version of the Subjective Vitality scale. Two different interventions are compared to a control condition in a randomized control design with first year psychology students (N = 58). The interventions differ in their assumed mechanism of action, which was a form of physical activity in one condition (15min brisk walk), and basic psychological need satisfaction in the other condition (strength-exploring interview).

Chapter 2

Chapter 2 explores the association between different levels of trait Subjective Vitality and RSFC in posterior cortical areas around the DMN (Raichle, 2015). Subjects are recruited online and invited based on their ”high” or ”regular” levels of trait Subjective Vitality in an online screening. For means of comparison, a group of participants with ”high” or ”regular” occurrence in flourishing, a second well-being measure, are also included in the study. All participants ($N = 43$) undergo a 7-min resting state period where cortical brain activity in the parietal and temporal cortices are measured using functional near-infrared spectroscopy (fNIRS). Networks of functional connectivity are calculated and compared between the different groups. Trait and state self-referential thoughts (rumination and mind-wandering), the degree of depressive symptoms, and mental activity during the measurement are considered as control variables.

Chapter 3

Chapter 3 examines changes in HRV standard parameters and state Subjective Vitality over the course of a Qi Gong exercise. Parameters of HRV, representing ANS modulation are analyzed to further define the state of Subjective Vitality from a physiological perspective. The exercise of Qi Gong was chosen due to its explicit focus on raising a person’s vitality as expressed in the conceptual framework of Traditional Chinese Medicine. Besides the consideration of acute physiological changes linked to changes in state Subjective Vitality, the recruitment of Chinese and German participants allows to further clarify phenomenological aspects of Subjective Vitality in comparison to the concept of Qi and related concepts from the Western literature. Participants ($N = 42$) in both countries practice two bouts of Qi Gong and undergo a resting condition while their heart rate is recorded and assessments of subject state before, after and in between each exercise are made. Furthermore, the consideration of age, Qi Gong experience and Qi Gong specific beliefs in both samples allows an examination of general and specific factors driving changes in state Subjective Vitality and its physiological correlates.

Chapter 4

Chapter 4 explores the interaction between daily Subjective Vitality, resting state vagal tone and associated health-factors in a field setting. Using an intense longitudinal design, daily levels of Subjective Vitality, habitual physical activity, vagal tone, basic psychological need satisfaction and symptom severity are monitored in eight patients with depression over residential psychotherapy. Via means of dynamic multilevel network analysis, within-day and lag-1 day associations between all variables are examined in the participants. Each patient’s trajectory of change in daily Subjective Vitality is examined to investigate patterns of change during therapy. Pre-post therapy changes in trait Subjective Vitality, aggregated physical activity and resting state vagal tone are examined and compared to a healthy control group.

Chapter overview

	Chapter 1	Chapter 2	Chapter 3	Chapter 4
Aim	Establishing a self-report instrument to measure vitality (Subjective Vitality)	Exploring a physiological correlate of trait Subjective Vitality	Exploring a physiological correlate of state Subjective Vitality	Exploring a physiological correlate of daily Subjective Vitality
Physiological correlate	-	RSFC in parietal and temporal areas of the DMN	HRV standard parameters (RMSSD, SDNN, HF, LF, VLF, coherence, SPcoherence)	HRV Vagal tone (HF)
Type of measurement	-	Resting state (7min)	Acute response during Qi Gong Pre-post resting state	Resting state (7min, daily)
Measurement instrument	-	fNIRS	ECG	ECG
Subjective Vitality	Trait & state	Trait	State	Daily & trait
Additional measures	Depression, anxiety, somatic symptoms, fatigue, life satisfaction, vigor-activity, work-activity time, leisure-activity time, psychological need satisfaction, positive affect	Flourishing, depression, trait & state rumination, trait & state mind-wandering, open-thought protocol	Subjective calmness, pleasant body sensation, focused attention, body awareness, perceived body activation, sensation of Qi, belief in Qi, belief in scientific investigatability of Qi	Daily physical activity (accelerometry), daily psychological need satisfaction daily individual symptom severity
Intervention	Strength-oriented interview (SEI) Brisk walk (15min)	-	Qi Gong (Baduanjin)	Residential Psychotherapy
Sample	Online convenience and student sample Study 1a: $N = 643$ Study 1b: $N = 56$	Healthy population sample $N = 43$ $n = 18$ high-vital $n = 25$ regular-vital	Healthy Qi Gong practitioners $N = 42$ $n = 21$ Chinese $n = 21$ German	In-patients with depression N = 8 (F32.1/F33.1)
Statistical analysis	PCA & CFA Correlational analysis Multiple regression Mixed ANOVA	Network-based statistics (NBS) Independent t-tests	Repeated measures ANOVA Correlational analysis Subgroup analysis	Wilcoxon signed rank test Man-Whitney-U test Multilevel dynamic network analysis (mlVAR) Linear model fitting Time-series complexity analysis

Note. ANOVA - analysis of variance; CFA - confirmatory factor analyis; DMN - default mode network; ECG - electrocardiography; HF - high-frequency power; HR - heart rate; HRV - heart rate variability; PCA - principal component analysis; RMSSD - root mean square of successive R-R differences; RSFC - resting state functional connectivity; SDNN - standard deviation of N-N intervals; VLF - very-low-frequency power.

Chapter 1

Vitality Measured by Self-report

Abstract

Over the last decade, the concept of Subjective Vitality has gained popularity as one indicator of human well-being. However, today no valid instrument exists to measure Subjective Vitality in German-speaking samples. To close this gap, we validated a German trait and state version of the Subjective Vitality Scale (Ryan & Frederick, 1997). Study one ($N = 632$) used an online survey to examine factorial validity of the existing 7-, 6- and 5- item versions of the scale (Kawabata et al., 2017) in German. Concurrent validity was tested via the relationship to convergent and divergent measures, external correlates and basic psychological need fulfillment. Study two used a student sample ($N = 58$) to test the scale's sensitivity to changes in state Subjective Vitality following two short interventions (brisk walk or strength-exploring interview) as compared to a control condition (objective self-description). We replicated acceptable model fit and the highest degree of parsimony for the 5-item version. Subjective Vitality as a trait showed negative relationships with measures of depression, anxiety, somatic symptoms and fatigue. Positive correlations were found for vigor, life satisfaction, weekly hours of leisure activity and feelings of competence, autonomy and relatedness. In contrast to the control condition, a 15 minute brisk walk and a strength-exploring interview increased state levels of Subjective Vitality in participants. With regard to scale characteristics, sensitivity and validity, the 5-item trait and state version of the Subjective Vitality scale in German is recommended as corresponding standard to their international counterparts.[1]

[1] The contents of this chapter are published: Goldbeck, F., Hautzinger, M. and Wolkenstein L. (2019). Validation of the German Version of the Subjective Vitality Scale - a Cross-Sectional Study and a Randomized Controlled Trial. *Journal of Well-being Assessment*, 1-21.

1.1 Introduction

Subjective Vitality in German-speaking samples

"Those who are filled with life, need not fear tigers and rhinos in the wilds" says semi-legendary sage Lao Tzu in the Tao Te Ching (Chapter 50, Merel Version). Long after being mentioned in this key scripture of ancient Taoism, modern science has turned towards "those, who are filled with life". With the rise of positive psychology (Seligman & Csikszentmihalyi, 2000) the concept of Subjective Vitality as the "conscious experience of possessing energy and aliveness" (Ryan & Frederick, 1997, p. 530) has become a prominent indicator of well-being as the "dynamic reflection of well-being" (Ryan & Deci, 2008, p. 529). Grounded in the theoretical framework of self-determination theory, Subjective Vitality as a concept has been used in a growing number of studies conducted in health (Kenyon et al., 2015), sports (Shepherd et al., 2015), education (Vlachopoulos, 2012) and organizational research (Hahn et al., 2012). Despite its increased use, no validated German version of the Subjective Vitality Scale (Bostic et al., 2000; Kawabata et al., 2017; Ryan & Frederick, 1997) exists to date. In order to close this gap, our main goal was to provide a validated German version of the Subjective Vitality Scale (SVS-G). The original authors have put forward a trait and a state version of the instrument that we evaluated in two separate experiments.

From Vitality to Subjective Vitality

Over the past thirty years distinct academic disciplines such as sociology (Collins, 1981), psychology (R. Thayer, 1987), medicine (Ware & Sherbourne, 1992) and business (Quinn et al., 2012) have turned towards the conceptualization of vitality. However, in the pursuit of an integrative concept of health and motivation, modern psychology has probably been most productive (e.g. Baumeister, 2002; Kaplan & Kaplan, 1989; Lorr & McNair, 1971; Richman et al., 2009; Ryan & Frederick, 1997). In comparison to other concepts, Subjective Vitality has gained prominence due to its relation to the widely applied self-determination theory framework (Deci & Ryan, 1985b, 2008), that offers specific hypotheses about the psychological circumstances enabling the subjective experience of vitality. Subjective Vitality has been described as the "conscious experience of energy, perceived as available to the self to harness and regulate purposive action" (Ryan & Deci, 2008). The explicit involvement of the self enables a conceptual distinction from states of mood, mere activation and arousal (Ryan & Bernstein, 2004). According to Deci and Ryan (2000), three innate psychological needs specify the conditions for the experience of Subjective Vitality: (1) The need for competence, understood as feeling effective in the interaction with one's own environment, (2) the need for autonomy, understood as feeling volitional rather than controlled by external factors, and (3) the need for relatedness as feeling significant and connected to others. Activities that satisfy these basic psychological needs should maintain or enhance the state of Subjective Vitality (Ryan & Deci, 2008).

The Subjective Vitality Scale

The items of the Subjective Vitality Scale were derived from a larger sample of items "concerning perceptions of having energy, zeal, interests, purposes in life, and feelings of aliveness" (Ryan & Frederick, 1997, p. 539). An Exploratory Factor Analysis revealed a single factor associated with feelings of energy and aliveness. The resulting seven items were assumed to reflect "an adequate definition of a phenomenological sense of aliveness and energy and thus were summed to create a variable labeled Subjective Vitality" (Ryan & Frederick, 1997, p. 540). Using structured equation modeling, Bostic et al. (2000) found an improvement in model-fit after the exclusion of the only negatively worded item ("I don't feel very energetic"). Kawabata et al. (2017) validated the 6- and 7-item but also a 5-item version in two Japanese and a Singaporean sample considering concerns about the content validity of one item ("I look forward to each new day") of the original-scale. They found comparable levels of fit for all three models in a Confirmatory Factor Analysis and recommended using the 5-item version based on content validity and parsimony.

Over time, the scale has been used in multiple different samples. Among student (Reis et al., 2000; Sheldon et al., 1996) and general population samples (Gunnell et al., 2013), specific groups such as patients with a variety of medical conditions (Dawes et al., 2014; Gumz et al., 2015; Kenyon et al., 2015; Rouse et al., 2015), military cadets (Souza et al., 2015) or elite athletes (Adie et al., 2012) have been assessed with the scale. Since its revision, the scale has been translated into ten different languages. With the majority of the studies still being conducted in English, versions of the scale also exist in French (Salama-Younes et al., 2009), Greek (Vlachopoulos & Karavani, 2009), Arab (Salama-Younes, 2011), Persian (Fini et al., 2010), Croatian (Rijavec et al., 2011), Portuguese (Gouveia et al., 2012), Spanish (León et al., 2013), Korean (Ju, 2017), Japanese (Kawabata et al., 2017) and Russian (Alexandrova et al., 2014). Schmuck et al. (2000) used the scale in a binational design with a German sample, however the authors did not report on any validation criteria.

The items of the scale have to be rated on a 7-point scale ranging from 1 (*not at all true*) to 7 (*very true*) in terms of how they "apply to you and your life at the present time". A trait version, asking for the participant's rating with regard to "life in general" or "the past month", has also been used (e.g. Reis et al., 2000; Ryan & Frederick, 1997). The following two studies were conducted to validate a German Version of the Subjective Vitality Scale. Study 1a used an online survey to assess factorial validity of the existing versions of the scale (7-,6-, 5 item) and replicate findings concerning the relationship to eight validation constructs used by the original authors (Ryan & Frederick, 1997). The goal of study 1b was to assess the scales' sensitivity towards two different kinds of short interventions. Based on the prior research both interventions were assumed to be capable of changing the participant's perceived status of Subjective Vitality. The two studies will be described separately and concluded in the overall discussion.

1.2 Study 1a

Introduction

Ryan and Frederick (1997) introduced the Subjective Vitality scale as a 7-item instrument comprised of questions loading on one single factor. Following structure equation modeling Bostic et al. (2000) suggested that factorial validity could be improved by taking out the only inverse item ("I don't feel very energetic"). More recently Kawabata et al. (2017) validated a 5-item version of the scale in response to questions raised about the content validity of another item (I look forward to each new day). They found comparable factorial and concurrent validity for the 7-, 6- and 5-item version of the Subjective Vitality scale in English and Japanese speaking samples. For reasons of parsimony the authors recommended the use of the 5-item version as a standard. As first step in the development of a SVS-G we wanted to replicate these findings, hence we translated all seven items of the original scale to assess factorial validity of all three versions in a German-speaking sample.

When Ryan and Frederick (1997) introduced the concept of Subjective Vitality, they tested its relationship to various convergent and divergent psychological constructs in a series of studies. This led to our hypotheses concerning the concurrent validity of the SVS-G. Depression, anxiety, fatigue and somatic symptoms were chosen as measures of divergent validity. Two main diagnostic criteria for depression are loss of interest and low mood as described in the Diagnostic and Statistical Manual of Mental Disorders (DSM 5, American Psychiatric Association, 2013). Both stand in contrast to the outlined definition of vitality. Anxiety is associated with feelings of tension and uncontrollable worry that should also be negatively related to vitality. Fatigue indicates loss of energy, whereas Subjective Vitality indicates access to energy. Ryan and Frederick (1997) found lower levels of Subjective Vitality in pain patients compared to a group of healthy matched controls; hence we expect the presence of somatic symptoms to be negatively related to Subjective Vitality.

The constructs of life satisfaction (Diener et al., 1985) and vigor (Lorr & McNair, 1971) were chosen as convergent measures. Since Subjective Vitality is conceived as one aspect of well-being and associated with a general appreciation of being alive, we expected to find a positive relationship with the general concept of life satisfaction. Furthermore, the mood state of vigor is operationalized by adjectives such as "energetic" or "lively" that resemble the state of Subjective Vitality. Hence, we also expected to find a positive relationship between vigor and Subjective Vitality.

Subjective Vitality has also been associated with behavioral measures, a link we wanted to confirm in the validation of the SVS-G. Ryan, Bernstein, et al. (2010) showed increased levels of Subjective Vitality during the weekend compared to normal work days. The authors explained this by the increase in opportunities for need fulfillment when pursuing self-determined leisure activities. We expected to find a positive relationship between the amount of time spend on leisure activities and trait levels of Subjective Vitality. In comparison, the authors did not find any relationship to the amount of working hours per week. This is explained by the fact that during work participants are less in control of opportunities for need fulfillment due to restricted self-selection of coworkers and activities.

One basic assumption in SDT is the relationship between Subjective Vitality and fulfillment of the three basic psychological needs for competence, autonomy and relatedness. We expected to find a positive correlation between each need and Subjective Vitality as a trait.

Methods

Participants

An invitation to participate in an online survey was distributed via posts in social media platforms and email to a panel of volunteer research participants at the University of Tübingen. The study was introduced as part of a project concerned with the relationship between attitudes towards life and activities in daily life. Participants had to be at least 18 years of age and provided informed consent before participation. Two 25€vouchers served as incentive to take part in the survey. Of the 975 participants who started the online survey, 644 finished. Twelve cases had to be excluded due to lack of informed consent and one case was excluded because of incomplete data.

The mean age among the remaining 632 participants was 32.5 years (SD = 12.5) with a range between 18 and 71. The sample consisted of 58% male and 42% female participants. Thirty-six percent indicated to be currently enrolled as Bachelor-, Master- or PhD student. Within the sample 35% of the participants worked full-time and 22% part-time. All features of the overall sample are displayed in Table 1.1.

Assessment and measures

Subjective Vitality All seven items of the original scale (Ryan & Frederick, 1997) were translated into German using a backward-forward approach. The first part was done by a German-British emigrant, blind to the purpose of the study. A bilingual native speaker, also blind to the purpose of the study, then translated the items back into English. Potential divergence in the wording was discussed with

Table 1.1. Demographic characteristics of the overall sample (N=632)

	Subcategory	N	%
Age	<25	252	39.9
	25-35	188	29.7
	36-55	150	23.7
	>55	42	6.6
Gender	Female	263	41.6
Working situation†	Student	283	44.8
	Full time	224	35.4
	Part time	142	22.5
	Other	107	16.9
Relationship status	Married	168	26.6
	Partnership	278	43.9
Highest level of eduction	Doctoral degree	21	3.3
	Master's degree/Diploma	186	29.4
	Bachelor's degree	96	15.2
	High school degree	144	22.8
	High school student	116	18.3
	No degree indicated	69	10.9

Note. † Participants could select multiple answers when indicating their current working situation.

Table 1.2. Items of the original Subjective Vitality scale (Ryan & Frederick, 1997) and their German translation

Item No	English	German
1	I feel vital and alive	Ich fühle mich vital und lebendig
2	I don't feel very energetic (r)	Ich fühle mich schlapp (r)
3	Sometimes I am so alive I just want to burst	Manchmal fühle ich mich so lebendig, dass ich platzen könnte
4	I have Energy and Spirit	Ich habe Energie und Elan
5	I look forward to each new day	Ich freue mich auf jeden neuen Tag
6	I nearly always feel awake and alert	Ich fühle mich fast immer aufmerksam und aufgeweckt
7	I feel energized	Ich fühle mich voller Energie

Note. 6-item version: Item 1, 3, 4, 5, 6 and 7 (Bostic et al., 2000); 5-item version: Item 1, 3, 4, 6 and 7 (Kawabata et al., 2017). The translations were carried out using a backward-forward approach.

the first author and settled. All seven items of the original scale and their German translations are displayed in Table 1.2. The 6-item version contains items 1, 3, 4, 5, 6, and 7 (Bostic et al., 2000), the 5-item version comprises the items 1, 3, 4, 6, and 7 (Kawabata et al., 2017). The items need to be rated on a 7-point rating scale, ranging from 1 (*not at all true*) to 7 (*very true*). In study 1a the trait version was used and participants were asked to answer with regard to "how those statements apply to you and your life in general".

Vigor-Activity The German version of the vigor-activity subscale of the Profile of Mood States (POMS; Albani et al., 2005a; Bullinger et al., 1990; Lorr & McNair, 1971) was used as a convergent construct. The scale consists of eight adjectives participants are asked to rate on a 5-point rating scale indicating how they have felt "during the past week including today". The full instrument aims at the assessment of transient and fluctuating moods, and enduring states of affect.

Life satisfaction Life satisfaction was assessed as a second convergent measure via the German version of the Satisfaction-with-life-Scale (SWLS; Diener et al., 1985; Glaesmer et al., 2011). The SWLS is a one-dimensional measure that consists of five items that have to be answered on a 7-point rating scale ranging from total agreement to total disagreement.

Depression Depression was assessed using a subscale of the German version of the Brief Symptom Inventory (BSI; Derogatis & Spencer, 1993; Franke & Derogatis, 2000). In six items the participants are asked to rate the degree of impairment they felt due to different symptoms of depression during the preceding week on a 5-point rating scale (*not at all – strongly*).

Anxiety For the assessment of anxiety we used the subscale anxiety of the BSI (Franke & Derogatis, 2000). The six items cover states of anxiety, tension and agitation. The answering format is a 5-point rating scale (*not at all – strongly*) to measure the degree of impairment felt due to the different symptoms.

Somatic symptoms The subscale somatization of the SCL-90 (Derogatis, 1977; Franke & Derogatis, 2002) was used to assess the felt impairment due to physical symptoms. Twelve items cover a broad spectrum of somatic symptoms, including head- and back pain.

Fatigue The scale to assess fatigue was also taken from the Profile of Mood states (Albani et al., 2005b; Lorr & McNair, 1971). As its positive counterpart, the vigor-activity scale, it consists of seven adjectives that need to by rated by the participant in terms of how strongly they were felt on a 5-point rating scale "during the last week, including today".

Relatedness The subscale "Appreciation through others" of the "Frankfurter Selbstkonzept Skalen" (FSKN; Deusinger, 1986) was used as a measure of the construct relatedness. The entire instrument consists of ten scales to measure cognitive, emotional and behavioral attitudes towards the self. It was assumed that appreciation through other people reflects perceived relatedness as defined by Deci and Ryan (2000). The scale consists of six items that focus on the perceived appreciation by one's social environment (strangers and family members). On a 6-point rating scale (*not at all – totally agree*) participants are asked to state their degree of agreement towards each statement.

Competence The "Allgemeine Selbstwirksamkeits Kurzskala" (ASKU; Beierlein et al., 2013) was used as an indicator of the self-perception of general competence in the participants. Three items measure self-efficacy in terms of how the individual thinks of his or her ability to cope with difficulties and problems in general. The instrument builds on the theory of self-efficacy (Bandura, 1977) and was validated as a short instrument for the economic use in large representative population surveys. On a 5-point-rating scale participants have to judge how well each statement applies to them (*not at all – strongly*).

Autonomy To assess the perceived autonomy of the participants, four items from the subscale Perceived Choice of the self-determination scale (SDS; Ryan & Connell, 1989; Sheldon & Deci, 1996) were used. The items ask the participants for the general perception of choice in their life (e.g. "I can choose what to do in my life"). The items were translated and adapted to fit the rating scale format used in the assessment of relatedness. One of the four items was reversed to control for response bias ("I often do things that I don't choose to do"). As for the other measures, the participants were asked to decide to what extent each statement applied to them.

External correlates The average amount of hours, spent weekly on working or studying and leisure activities, were used as external correlates for the validation of the scale. The questions were developed for this study and reviewed by six test participants.

Statistical Analysis

A principal component analysis was done to confirm a one-factor solution for the German sample. Confirmatory factor analysis (CFA) was then conducted to assess factorial validity of the proposed 5-, 6-, and 7-item versions of the scale. As the data significantly deviated from a normal distribution, $W = 0.94$, $p < .001$, robust maximum likelihood estimation was used and robust chi-square statistic (MLM$\mathcal{X}^2$), comparative fit index (CFI; Bentler, 1990), Tucker-Lewis index (TLI; L. R. Tucker & Lewis, 1973), the root mean square error of approximation (RMSEA; Steiger, 1990), standardized root mean square residual (SRMR) and Akaike information criterion (AIC; Akaike, 1987) were calculated to assess goodness of fit of the models. In the assessment of model fit we followed the approach of Kawabata et al. (2017), who used values greater than .90/.95 as acceptable/excellent fit for CFI and TLI and values smaller than .05/.08 as close/adequate fit. We also followed recommendations of values $\leq .80$ for SRMR and a multiple indicator strategy in the process of model evaluation (Hu & Bentler, 1999). Standardized factor loadings were examined for the assessment of fit on the level of individual items. Based on the results of the CFA and building on former work (Kawabata et al., 2017) we then used the 5-item version for further analysis.

Prior to the main analysis of concurrent validity a multiple regression was conducted in order to test for the influence of age, gender and student status on Subjective Vitality. Similar to the approach taken by Ryan and Frederick (1997), the main effects were entered, followed by the interactions of gender and age, and gender and student status. The overall model did not reach significance, $F_{(5,626)} = 0.65$, $p = .66$. Hence, neither age, gender or student status, nor their interactions exerted a significant influence on Subjective Vitality. For the following analyses the data were collapsed over all three factors.

Table 1.3. Factorial validity and goodness of fit for the 5-, 6- and 7-item version of the Subjective Vitality scale in German (SVS-G)

	Modell description	MLM$\mathcal{X}^2$	*df*	CFI	TLI	RMSEA	RMSEA90% CI	AIC	SRMR
M1	7-item model	74.95	14	.965	.947	.097	[.076, .119]	12,426.35	.035
M2	6-item model (M1 - item 2)	62.00	9	.963	.938	.117	[.091, .146]	10,385.22	.038
M3	5-item model (M2 - item 5)	50.37	5	.961	.921	.143	[.108, .180]	8810.67	.038

Note. M1 - Model 1; M2 - Model 2; M3 - Model 3; MLM$\mathcal{X}^2$ - Robust Chi Square Maximum Likelihood statistic; CFI - Robust Comparative Fit Index; TLI - Robust Tucker-Lewis Index; RMSEA - Robust Root Mean Square Error of Approximation; RMSEA 90% CI - RMSEA 90% confidence interval; AIC - Akaike Information Criterion; SRMR - Standardized Root Mean Square Residual.

Correlational analyses and multiple regression analyses with random sampling bootstrap procedure (n = 2000) were used to assess concurrent validity of the Subjective Vitality construct.

Following the recommendations of Cohen (1992), Ryan and Frederick (1997) found medium and large effect sizes for their correlations with vitality. Miles and Shevlin (2001) state that in order to find a medium effect size in multiple regression with up to 20 predictors a sample size of 200 is sufficient. IBM SPSS 22.0 and R 3.0.2 were used as software for the analysis. All data is available at https://doi.org/10.17026/dans-xnk-g3ym

Results

Psychometric characteristics and factorial structure

Using all seven items initial principal component analysis supported a one-factor solution following Kaiser's Criterium of an Eigenvalue greater one. The Eigenvalue for the first component was 4.23 and explained 60.4% of the variance. The CFA yielded an acceptable model fit (all indicators except RMSEA) for all three scale versions (Table 1.3) with an advantage in AIC for the 5-item version. Cronbach's Alpha for all scales indicated sufficient internal consistency ($>$.80). The standardized factor loadings of all seven items were statistically significant ranging from 0.46 (item 3) to 0.91 (item 7) with a mean of 0.80 (Table 1.4). The following results are based on findings for the five item version.

The distribution of vitality scores in the overall sample turned out to be negatively skewed (-0.94) with a mean of 26.26 (SD = 4.96). Except for the three lowest scores every possible value was attained. The trend towards a positive degree of vitality was also reflected by the item means, that range above the scale midpoint of 4, from

Table 1.4. Descriptive statistics for the 5-, 6- and 7-item version of the Subjective Vitality scale in German (SVS-G) and single item psychometric characteristics based on the confirmatory factor analysis for the 7-item version of the scale

Version	*M*	*SD*	Skewness	Kurtosis	Cronbach's α
7-item	36.37	6.84	-0.89	0.77	.87
6-item	31.59	5.86	-1.00	1.15	.86
5-item	26.26	4.96	-0.94	0.99	.83
Item	*M*	*SD*	Item-scale correlation	Standard factor loading	Standard residual variance
Item 1	5.75	1.10	.80	0.80	0.37
Item 2†*	4.78	1.51	.71	0.62	0.61
Item 3	4.73	1.67	.61	0.46	0.79
Item 4	5.57	1.08	.83	0.82	0.32
Item 5*	5.33	1.2	.78	0.75	0.44
Item 6	5.05	1.29	.75	0.74	0.46
Item 7	5.17	1.20	.89	0.91	0.17

Note. M - Mean; *SD* - Standard deviation; † Item omitted for 6-item version; * Item omitted for 5-item version.

4.73 (item 3) to 5.75 (item 1). The item-total-correlations range from r = .61 to r = .89, indicating a sufficient amount of shared variance with the overall scale. All item characteristics are shown in Table 1.4.

Convergent and divergent validity

Table 1.5 shows the correlations, standard errors and confidence intervals of Subjective Vitality with convergent and divergent measures, external correlates and the three needs. Effect sizes are reported with regard to Cohen (1992). Small significant effect sizes were found for depression (r = -.19), anxiety (r = -.20), and fatigue (r = -.23). Somatic symptoms yielded a medium sized relationship with Subjective Vitality (r = -.47). As expected for measures of divergent validity all relations turned out to be negative. In the convergent group vigor-activity showed a significant positive relationship to Subjective Vitality with a small effect size (r = .16). Life satisfaction revealed a significantly large correlation (r = .56). Among the external correlates only the amount of actively spent leisure time reached a significant relationship with Subjective Vitality (r = .10). All three needs showed a positive relationship of medium size ($r_{competence}$ = .42; $r_{autonomy}$ = .43; $r_{relatedness}$ = .42). The confidence intervals confirm the findings, as for all non-significant values

Table 1.5. Correlation of Subjective Vitality (5-item Version) with divergent and convergent constructs, external correlates and basic psychological needs

Construct	*r*	*p*-value	*SE*	95% CI (Bootstrap)
Divergent Validty				
Depression	-.19***	<.001	0.04	[-.27, -.12]
Anxiety	-.20***	<.001	0.04	[-.28, -.13]
Somatic Symptoms	-.47***	<.001	0.04	[-.54, -.39]
Fatigue	-.23***	<.001	0.04	[-.31, -.16]
Convergent Validity				
Life satisfaction	.56***	<.001	0.04	[.48, .63]
Vigor-Activity	.16***	<.001	0.04	[.08, .24]
External Correlates				
Working Activity (hours/week)	.07	.062	0.04	[0, .15]
Leisure Activity (hours/week)	.10**	.008	0.03	[.03, .17]
Basic Psychological Needs				
Competence	.42***	<.001	0.04	[.33, .50]
Autonomy	.43***	<.001	0.04	[.34, .51]
Relatedness	.42***	<.001	0.04	[.34, .49]

Note. N = 632; Depression - Subscale depression of the Brief Symptom Inventory (BSI); Anxiety - Subscale anxiety of the Brief Symptom Inventory (BSI); Somatic Symptoms - Subscale Somatization of the Symptom Checklist 90 revised (SCL-90-R); Fatigue - Subscale of the Profile of Mood States (POMS); Vigor - Subscale Vigor-Activity of the Profile of Mood States (POMS); 95% CI (Bootstrap) - 95% confidence intervall of estimated correlation parameter using 2000 bootstrap samples [lower bound, upper bound]; ***p<.001; **p<.01, two-tailed.

they include zero.

Basic psychological needs

A multiple regression was conducted to assess the strength of the three basic needs as predictors for Subjective Vitality. All three predictors were centered around their mean, since none of the scales included zero. Autonomy (β = 0.25), relatedness (β = 0.20) and competence (β = 0.25), all p < .001, explained 29% of the variance in Subjective Vitality (R^2 = .29, $F_{(3,631)}$ = 86.92, p < .001). The standardized and non-standardized coefficients for each model are shown in Table 1.6.

Discussion Study 1a

Study 1a served to examine basic psychometric and factorial characteristics of the SVS-G and to replicate relationships that have been found for English speaking samples. The overall frequency distribution of Subjective Vitality revealed a positive skewedness which is characteristic for measures of well-being (Diener et al., 2013).

Table 1.6. Subjective Vitality predicted from basic psychological need fullfilment (mean-centered)

Predictor (N=632)	B	SE B	β	p	M	SD
Constant	26.25	0.17				
Autonomy	0.41	0.06	.25***	<.001	19.22	3.02
Relatedness	0.23	0.1	.20***	<.001	28.80	4.39
Competence	0.67	0.04	.25***	<.001	13.22	1.87

Note. R^2 = .29; R^2 adjusted = .29; B - Non-standardized regression coefficient; β - Standardized regression coefficient; M - Mean; SD - Standard Deviation; Autonomy - Adjusted items from the self-determination scale (SDS); Relatedness - Subscale "Appreciation through others" of the "Frankfurter Selbstkonzept Skalen" (FSKN); Competence - "Allgemeine Selbstwirksamkeits Kurzskala" (ASKU); ***p <.001.

Factorial validity and internal consistency for the 5-, 6- and 7-item version of the SVS-G are sufficient and comparable to their international counterparts (Bostic et al., 2000; Kawabata et al., 2017; Ryan & Frederick, 1997). The five item version of the SVS-G showed the expected positive correlations with vigor-activity and life satisfaction as well as the expected negative correlation with measures of depression, anxiety, somatic symptoms and fatigue. These findings are in line with the results from the original studies of Ryan and Frederick (1997) who found negative correlations for Subjective Vitality with constraints in body-functioning and positive correlations with life-satisfaction. The results are also in line with more recent findings of a negative relation between Subjective Vitality and health restraints (Dawes et al., 2014; Gumz et al., 2015; Kenyon et al., 2015; Rouse et al., 2015) and a positive relation with life-satisfaction (Tremblay et al., 2006; Uysal et al., 2014). With regard to the external correlates, a significant positive correlation was found for the average amount of time individuals spend on leisure activities per week. This is in line with findings of Molina-García et al. (2011). In contrast, no significant relationship was found for the amount of hours, spent weekly on working or studying. This difference between time spent on work and leisure activities confirms findings by Ryan, Bernstein, et al. (2010) who explain their findings by differences in psychological need satisfaction. In this study, the three basic needs for competence, autonomy and relatedness all predicted Subjective Vitality in a significant way.

1.3 Study 1b

Introduction

The second study served to validate the state version of the SVS-G. This was done by testing the scale's sensitivity to capture changes in Subjective Vitality following two short interventions. State Subjective Vitality has shown to be increased by exposure to nature or forest environments (Ryan, Weinstein, et al., 2010; Takayama et al., 2014; Tyrväinen et al., 2014), moderate walking (Thøgersen-Ntoumani et al., 2014) or exercise (Duda et al., 2014), visionary coaching (Passarelli, 2015), autogenic training (Ortigosa-Márquez et al., 2015), energy imaginary (Thøgersen-Ntoumani et al., 2012), self-reflexive writing on intrinsic values (Lekes et al., 2012) or by the visualization and writing about a person with former or current close secure relationship (Rowe et al., 2016). Overall, activities that meet a person's need for autonomy, relatedness or competence are assumed to elevate levels of Subjective Vitality (Ryan & Deci, 2008). This has been shown in a diverse array of settings such as sports (Felton & Jowett, 2013), education (Núñez & León, 2016) or work (Graves & Luciano, 2013).

For this study, we chose two interventions with high ecological validity but presumably different mechanisms of action: a 15 minute brisk walk and a strength exploring interview (SEI). Both conditions were compared in form of a randomized controlled trial to a control intervention that was assumed not to influence levels of Subjective Vitality.

The walking intervention was selected due to its reliable effect on levels of perceived energy and Subjective Vitality (Ryan, Weinstein, et al., 2010; Thøgersen-Ntoumani et al., 2014; R. Thayer, 1987). The SEI was chosen to rule out the explanation of a mere increase in physiological arousal as reason for changes in Subjective Vitality. Instead, the goal of this intervention was to increase Subjective Vitality by means of psychological need fulfillment. Individuals filled out a questionnaire of character strengths and were interviewed afterwards by another person about what their personal strengths were and how they could be applied in daily life. The entire procedure served to elevate levels of perceived competence and relatedness. The control group was asked to write down a description of their outer appearance which was assumed to neither lead to changes in physiological arousal nor psychological need fulfillment. We hypothesized that the walking intervention and the SEI would increase levels of state Subjective Vitality whereas Subjective Vitality of the participants in the control group would remain constant throughout the experiment.

Methods

Sample

Fifty-eight undergraduate students from the fields of Psychology and Cognitive Science were recruited via announcements in lectures at the University of Tübingen. The experiment was described as a new form of diagnostics, the participants would have to evaluate. In order to participate, the students had to sign up for one out of six occasions to come to the laboratory. Seventy-nine percent of the participants were female, the mean age was 22.8 ($SD = 6.5$). The students could receive course credit for their participation, no other incentives were provided.

Measures and material

Subjective Vitality Subjective Vitality was measured with the 5-item version of the Subjective Vitality Scale, as described in study 1a. However, this time a state version was used. Here, participants are asked to answer the six items with regard to "how well each statement applied to them at this moment".

Positive affect Positive affect was assessed with the Positive and Negative Affect Scale (PANAS; Watson et al., 1988) for which a validated German version has been adapted by Krohne et al. (1996). The questionnaire measures positive and negative affect with ten adjectives for each dimension. Only the subscale positive affect was used as a control measure in the analysis. The scale reflects the extent to which a person feels enthusiastic, active and alert (Watson et al., 1988). The items are rated on a 5-point rating scale (*not at all – very much*) in terms of how strongly participants perceived the intensity of the according adjective at this moment.

Character-strengths In order to give the participants a starting point for the interview, the SEI group received the Values-in-Action inventory (VIA) for the assessment of individual character strengths (Ruch et al., 2010; Seligman, 2012). The instrument contains 48 statements (e.g., "I am always curious about the world") to be rated on a 5-point rating scale (*not like me at all – very much like me*). To reliably evoke feelings of competence during the short time of the interview we used the inventory to give a standardized initial focus on one's individual strengths independent of the following interview.

Interview materials For the strength exploring interview eight guiding questions were provided to help the participants assessing the strengths of the interview partner. The questions focused on (1) naming a strength, (2) asking for specific situations, in which it had been applied, (3) other life stories connected to this strength, (4) feelings and thoughts associated with it, (5) reactions of the environment when this strength was applied, (6) how the person would call the character trait behind this strength (7) how its influence in one's personal life could be increased in the future and (8) to choose a good symbol for the strength. The questions were designed to increase the salience of competence in participants.

Covariates As states of affect and vitality have shown to be sensitive to exercise, diet and diurnal rhythm (R. Thayer, 2001), estimates for the duration of time since the last meal, the last time the person sweated and the duration of sleep during the last night were collected as covariates after the intervention.

Procedure

The participants were assessed in groups of five to 15 people. The three conditions were randomly assigned to two out of the six occasions that the participants had signed up for. All sessions were scheduled between 12 and 2 o'clock in the afternoon. After arriving at the room, the participants were greeted by the experimenter and received information materials about the study and informed consent was obtained. An opportunity to ask questions was provided and the experimenter announced that the session would take place in three phases. For each phase the participant's would receive an instruction with the according materials. Every phase would be announced with a time limit by the experimenter and the group would only proceed into the next phase, after all participants had finished. The experiment lasted approximately one hour. Demographical data was collected at the beginning of the test session. In phase one, participants in all three groups received vitality and affect measures for baseline assessment. Phase two consisted of the intervention. In phase three post intervention levels of all measures and information on the covariates were assessed.

Intervention

Strength-exploring interview (SEI) condition In the first experimental condition the group underwent a strength-exploring interview procedure. The first part of the intervention consisted of the VIA inventory for the self-assessment of values and character strengths. The participants were asked to fill it out and calculate their results. Upon completion the instructor handed out the second part of the instruction that told participants to imagine that they were called in as interview-specialist for the conduction of a strength-exploring assessment of the person seated next to them. Their goal was to identify one or two key strengths of the interview partner and gather as much information as possible about those strengths. Furthermore, the construction contained the hint to not let the partner's modesty keep them away from reaching their goal and that roles would be switched after 15 minutes. In the end participants were supposed to be prepared to give a short introduction of their partner's strengths to a group of people. A sheet with eight guiding questions was part of the materials provided and participants were told that its use was optional. The participants were asked to take notes, which served as manipulation check for the analysis. After 30 minutes the experimenter asked each pair to join another pair for a one-minute introduction of their partner. Upon completion of the introduction, everyone received the post-intervention measures.

Walking condition In the second condition the participants were instructed to take a 15 minutes brisk walk outside. They were asked to walk alone and use this opportunity to calm down. As manipulation check the questionnaire on covariates in this group contained the task to take a short note on their route and estimate the number of steps taken.

Self-description condition The control group received the task to prepare a self-description, using full sentences or key words. The instruction asked the participants to provide a description of their outer appearance that should enable a stranger to draw them in as much detail as possible. For standardization purposes the description should be a full body description in an upright standing position, the arms at the side of the body and with a neutral facial expression. The participants were asked to complete the task within 15 minutes time and the descriptions were collected for the means of manipulation check. The task of a self-description in pure technical terms was intended to not evoke vitality related thoughts or feelings, hence to keep the participants in a neutral condition.

Data analysis

Mixed analyses of variances (ANOVAs) were applied to compare changes of Subjective Vitality in the three conditions. The measure of positive affect was used as reference manipulation check. Pre-intervention levels of Subjective Vitality and positive affect were used as covariates to control for differences in initial scores of the relevant variables. Planned contrasts were used to test for differences between the three conditions. Food intake, exercise and duration of sleep have shown to be influential with regard to perceived levels of energy (R. Thayer, 2001). In this study, they showed no significant correlation with pre-and post-intervention Subjective Vitality levels ($p > .10$) so we did not include them in the further analysis. IBM SPSS 22.0 and R 3.0.2 served as software for the analysis. All data is available at https://doi.org/10.17026/dans-xnk-g3ym

Table 1.7. Means (Pre-Post intervention) and Adjusted Means for Subjective Vitality and Positive Affect in all Three Groups of Study 1b

	Subjective Vitality					Positive affect				
Condition	*M* pre	*M* post	*M* adj.	*SE*	95% *CI*	*M* pre	*M* post	*M* adj.	*SE*	95% *CI*
Strength-exploring interview (SEI)	22.0	24.09	23.95	0.31	[23.34, 24.56]	32.50	36.05	35.62	1.23	[33.15, 38.09]
Walking	24.44	26.37	23.94	0.36	[23.22, 24.66]	32.88	35.19	34.48	1.44	[31.58, 37.38]
Self-description	22.75	22.5	22.8	0.32	[22.16, 23.44]	30.55	30.60	31.63	1.29	[29.03, 34.24]

Note. *M* pre - group mean pre-intervention; *M* post - group mean post-intervention; *M* adj. - adjusted group mean based on average per-intervention score of 22.93 (Subjective Vitality) and 31.93 (positive affect) for means of comparability between conditions; 95% CI - 95% confidence interval for adjusted mean [lower bound, upper bound].

Results

Preliminary results

Using Kolmogorov-Smirnov test, the assumption of normality was met for pre- and post-vitality scores and scores of positive affect in all three groups ($p > .05$). A single factor ANOVA revealed the SEI-group (M = 21.2; SD = 5), the walking-group (M = 20.6; SD = 2.3) and the self-description-group (M = 24.2; SD = 8.1) did not differ significantly with regard to age, $F_{(2,54)} = 1.74$, $p = .18$. The groups did differ significantly in their ratio of male and female participants, $\mathcal{X}^2(2, 57) = 6.2$, $p = .045$. The SEI-group ($N = 22$, $n_{male} = 8$), the walking-group ($N = 16$, $n_{male} = 1$) and self-description-group ($N = 20$, $n_{male} = 3$) all had less male than female participants.

Subjective Vitality

Overall, we found a significant interaction of changes in Subjective Vitality and experimental condition, $F_{(2,54)} = 4.23$, $p = .02$, partial $\eta^2 = .14$. Planned contrasts revealed that the SEI condition, $p = .021$, 95% CI [0.18, 2.11] and the walking condition, $p = .012$, 95% CI [0.26, 2.03] significantly increased Subjective Vitality compared to the control condition (self-description). Pre-and post-SV scores for all three conditions are displayed in Figure 1.1. The descriptive statistics as well as the pre-intervention Subjective Vitality score adjusted means for better comparison between conditions are displayed in Table 1.7.

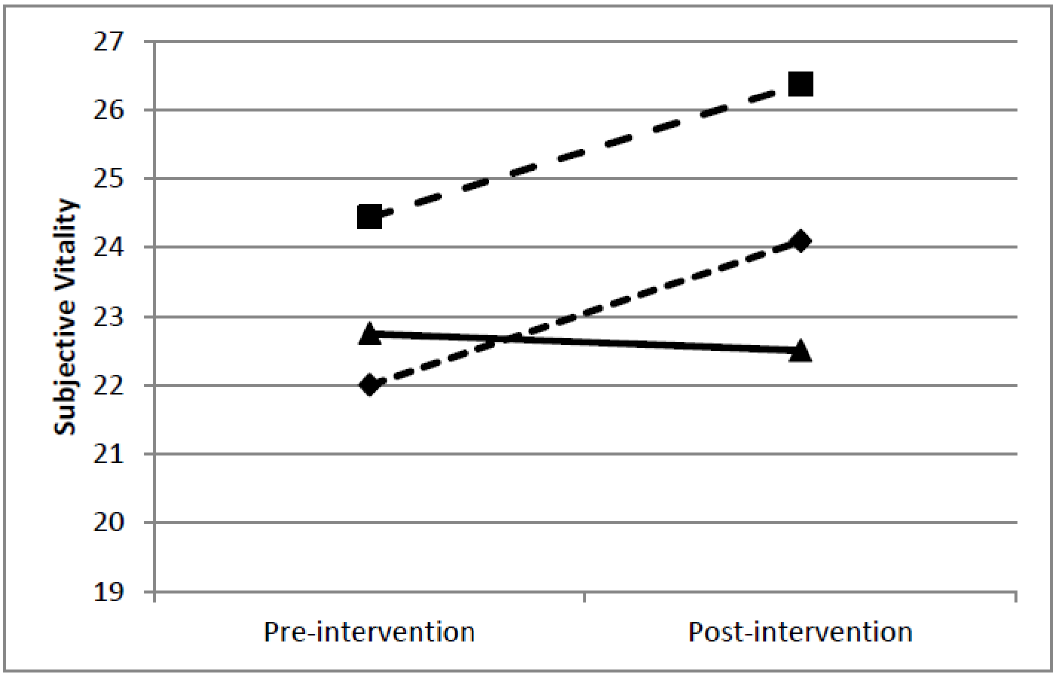

Figure 1.1. Changes in Subjective Vitality for the strength-exploring interview (SEI) group (♦), the walking group (■) and the self-description/control group (▲)

Positive affect

For positive affect, we found a similar tendency of a significant interaction between changes in positive affect and experimental condition, $F_{(2,54)} = 2.56$, $p = .087$, partial $\eta^2 = .09$. Planned contrasts revealed that in the SEI condition, $p = .03$, 95% CI [0.19, 3.79] positive affect was significantly higher after the intervention compared to the control condition (self-description). The walking condition did not differ significantly from the control condition, $p = .15$, 95% CI [-0.53, 3.38]. The descriptive statistics are displayed in Table 1.7.

Discussion Study 1b

Study 1b aimed at testing a state version of the Subjective Vitality Scale for its sensitivity to capture changes in Subjective Vitality and positive affect. Participants who either engaged in a 15 minute brisk walk or a strength-exploring interview reached significantly higher levels of Subjective Vitality than a control group after adjustment for covariate baseline levels. The findings for the walking intervention are in line with studies that found a positive influence of shorts walks on Subjective Vitality (Thøgersen-Ntoumani et al., 2014; R. Thayer et al., 1993; Tyrväinen et al., 2014). This was the first study to assess the acute influence of a strength-exploring interview on Subjective Vitality. The results may be most similar to the effect of visionary coaching which touches upon a participant's strengths and resources and has been linked to changes in Subjective Vitality (Passarelli, 2015). No difference was found between the two intervention groups. Also, positive affect showed to be significantly increased by a strength-exploring interview. In the walking condition only a tendency for improvement was visible. The overlap of the confidence intervals and larger standard errors for positive affect reveal that a large variance in this rather small sample may have prevented a significant result. For the Subjective Vitality scale, sensitivity towards the two interventions can be concluded. Further details will be discussed in the overall discussion.

1.4 Discussion

The goal of this paper was to validate a state and trait version of the German Subjective Vitality Scale. Two studies were conducted in order to examine the scale's factorial and concurrent validity as well as its sensitivity to a physical and psychological intervention. Our analysis of factorial validity yielded an acceptable model fit for the 7-, 6- and 5-item version of Subjective Vitality scale in German and comparable results to other language versions (Kawabata et al., 2017). Using the 5-item version of the scale, the Study 1a found positive relations to vigor-activity and life satisfaction on the one hand and significant negative relations to measures of depression, anxiety, fatigue and somatic symptoms on the other hand. The amount of hours spent weekly on working/studying or on leisure activities were used as external correlates and yielded the expected positive relation for time spent on leisure activities. The core assumption of SDT that levels of Subjective Vitality are positively related to differences in basic psychological need fulfillment was tested and confirmed for trait levels of perceived competence, autonomy and relatedness. Using multiple regression analysis all three needs proved to be significant independent predictors of Subjective Vitality.

Study 1b tested the scale's sensitivity to state changes using a physical and a psychological intervention. A 15 minute brisk walk and a strength-exploring interview led to significant increases in Subjective Vitality compared to a control intervention. Overall, all key hypotheses in the validation process were met. However, in various cases effects sizes did not turn out as large as in the original experiments. Possible reasons and further aspects will be discussed in the following sections.

Overall, correlations were in a similar direction, however smaller in size than the ones attained by Ryan and Frederick (1997) were found in study 1a. Depression, anxiety, fatigue and vigor revealed only small effect sizes between |.12| and |.22|, whereas the authors in the original studies found moderate to large effect sizes between |.38| and |.69|. The decrease of effect sizes over time is a known phenomenon in empirical psychology (Schooler, 2011). One argument is the increase in sample sizes compared to earlier studies. The sample size in study 1a was considerably larger than the one used by Ryan and Frederick (1997), hence one potential explanation for the decrease in effect sizes is a more accurate estimate of the effect size due to higher statistical power. Another potential reason is the use of different measures. The present study used brief measures for depression, anxiety and somatic symptoms for reasons of economic validity which were different in wording, shorter and in the case of fatigue and vigor different with regard to time framing (last week including today vs. last month) than those used in the original studies.

However, the lower correlations could also be the result of cultural differences. Germans and US citizens differ significantly in their levels of reported subjective well-being (Westerhof & Barrett, 2005). This is indicated by lower levels of reported positive affect and life satisfaction and higher levels of reported negative affect in national German samples. On the other hand, prevalence rates for depression and anxiety disorders in Germany are not higher than in the United States (Andrade et al., 2000), but the open expression of happiness and liveliness might not be regarded as socially desirable as in the United States (Diener, 1994). Further research on the role of culture as moderating factor regarding the strength of associations between Subjective Vitality and other concepts would be necessary to evaluate this explanation for differences in effect sizes between our and the original study.

Despite the decreases in effect size, it can be concluded that the measure at hand can be regarded as a valid German version for the measurement of Subjective Vitality as a trait.

From the perspective of self-determination theory, changes in Subjective Vitality are explained by changes in the fulfillment of basic psychological needs. This was the mechanism assumed to underlie changes in Subjective Vitality following the strength-exploring interview. Other studies showed a relation between walking and levels of Subjective Vitality (Ryan, Weinstein, et al., 2010; Thøgersen-Ntoumani et al., 2014; R. Thayer, 1987) which we replicated in study 1b. However, a link between everyday walking and psychological need fulfillment is not obvious and no alternative mechanism for the effect has been proposed from an SDT perspective. We did not assess the effect of our interventions on psychological need fulfillment but in order to increase the understanding of the mechanism behind acute changes in Subjective Vitality, future research should include this option.

R. Thayer (1987) proposed the feeling of energy to be a conscious representation of general bodily patterns of arousal, evoked by exercise. He brought into play the physiological perspective, relating a broad range of energy expending processes (e.g., cell metabolism, heart rate, blood pressure, infusion of neurotransmitters) to the subjective experience of energy. Furthermore, in his biopsychological model of energy he showed how the perceived energy to move, to act and to do things depends on factors like diet, sleep and exercise (R. Thayer, 2012). Now that we can reliably measure changes in state Subjective Vitality, further research on Subjective

Vitality and its physiological correlates may be a promising approach to improve our understanding of acute changes in Subjective Vitality and integrate formerly separate findings.

Before drawing final conclusions, some limitations of our studies have to be kept in mind. The online survey in study 1a was distributed using university e-mail lists and social media. Hence, despite a broad age range and a high diversity of educational and occupational backgrounds, the representativeness of the sample is limited.

The sample in study 1b consisted mainly of undergraduate psychology students, which limits the generalization of these findings. Moreover, the sample was mostly female so that we could not consider the possible influence of gender. Furthermore, the session instructor was not blind to the purpose of the study, so despite all main instructions being provided in a written format, the potential occurrence of experimenter effects has to be considered with regard to our findings.

Despite these limitations, we provide the first validated German version of the Subjective Vitality Scale to enable the assessment of those who are "filled with life" in German-speaking samples. The data, as attained within the two studies, suggests that Subjective Vitality is a valid candidate for future research at the intersection of psychological and physiological processes. It is sensitive to interventions and reflective of conditions of basic psychological need fulfillment in German samples.

Chapter 2

Trait Subjective Vitality and Brain Activity

Abstract

The World Health Organization has defined health as "complete physical, mental and social well-being and not merely the absence of disease or infirmity" (Preamble to the Constitution, 1948). An increasing number of studies have therefore started to investigate *the good life*. However, the underlying variation in brain activity has rarely been examined. The goal of this study was to assess differences in resting state functional connectivity (RSFC) between regular healthy individuals and healthy individuals with a high occurrence of flourishing and Subjective Vitality. Together, flourishing, a broad measure of psycho-social functioning and Subjective Vitality, an organismic marker of subjective well-being comprise the phenomenological opposite of a major depressive disorder. Out of a group of 43 participants, 20 high-flourishing (highFl) and 18 high-vital (highSV) individuals underwent a 7-minute resting state period, where cortical activity in posterior brain areas was assessed using functional near-infrared spectroscopy (fNIRS). Network-based statistics (NBS) of FC yielded significantly different FC patterns for the highFl and highSV individuals compared to their healthy comparison group. The networks converged at areas of the posterior default mode network and differed in hub nodes in the left middle temporal/fusiform gyrus (flourishing) and the left primary/secondary somatosensory cortex (Subjective Vitality). The attained networks are discussed with regard to recent neuroscientific findings for other well-being measures and potential mechanisms of action based on social information processing and body-related self-perception.[2]

[2]The contents of this chapter are published: Goldbeck, F., Haipt, A., Rosenbaum, D., Rohe, T., Fallgatter A.J., Hautzinger, M. and Ehlis A.-C. (2019). The Positive Brain - Resting State Functional Connectivity in Highly Vital and Flourishing Individuals. *Frontiers in human neuroscience*, 12, 540.

2.1 Introduction

We know a lot more about the things that can go wrong in life than about the good life (Seligman & Csikszentmihalyi, 2000). For the field of human neuroscience, despite major contributions over the last years (Berridge & Kringelbach, 2015; Burgdorf & Panksepp, 2006; Greene & Seligman, 2016; Heller et al., 2009; Heller et al., 2013; Kong, Hu, Wang, et al., 2015; Kong, Hu, Xue, et al., 2015; Kong, Liu, et al., 2015; Kong et al., 2016; Kringelbach & Berridge, 2009; Sato et al., 2015; Van Reekum et al., 2007), this is still true. As in the case of psychological disorders, the good life consists of and is being measured in multiple aspects (Peterson et al., 2005; Ryan & Deci, 2001). Two widely used concepts, whose neurophysiological signatures are still unknown, are the constructs of flourishing (Diener et al., 2010; Keyes, 2002; Seligman, 2012) and Subjective Vitality (Ryan & Frederick, 1997). The term flourishing (Fl) has been used to describe a broad array of distinct dimensions of positive psycho-social functioning (Diener et al., 2010; Fredrickson & Losada, 2005; Keyes, 2002; Seligman, 2012; VanderWeele, 2017) whereas Subjective Vitality was introduced as a narrow construct to measure a person's perception of energy, available for mental and physical action (Ryan & Deci, 2008).

In combination, the two concepts mirror the positive opposites of the main non-somatic criteria present in a major depressive episode (Huppert & So, 2013): Feeling competent and engaged, perceiving life as meaningful and being optimistic, experiencing positive emotions, having satisfying relationships and feeling alive and energetic. A healthy person who scores high on these dimensions compared to a healthy person with low scores shows fewer missed days of work, a lower risk for cardiovascular and chronical physical disease and fewer health limitations in daily life activities with age (Keyes, 2007; Pressman & Cohen, 2005). However, despite these findings concerning health and daily life behavior, the differences in human brain activity underlying different levels of flourishing and Subjective Vitality have only scarcely been examined. This paper aims at contributing to fill this gap by looking at the neural correlates of flourishing and Subjective Vitality in the brain at rest. We did so via the comparison of high-flourishing and high-vital individuals with a group of healthy but regular-flourishing/vital (regFl/regSV) subjects. Flourishing and Subjective Vitality were measured using validated self-report measures (Diener et al., 2010; Ryan & Frederick, 1997). Median split groups were derived for the purpose of group comparison. Both measures, Fl and SV, contain aspects of the good life and will be referred to as concepts belonging to the broader area of well-being measures.

Psychological disorders have been studied extensively from a neuroscientific perspective. Hence, we used associated methods and corresponding theories as a starting point for the design and hypotheses in this project. In depression research, recently much attention has been given to changes in resting state functional connectivity (FC; Mulders et al., 2015; L. Wang et al., 2012), changes in the temporal correlations of spontaneous brain activity in spatially remote areas in the resting brain (Friston et al., 1993). Some first studies in the field of well-being research also found significant changes in FC associated with happiness (Wayne et al., 2018), eudaimonic and hedonic well-being (Luo et al., 2017). The majority of changes thereby occurred in areas of the default mode network (DMN; Greicius et al., 2003). The DMN anatomically consists of precuneus, adjacent posterior cingulate/retrosplenial cortex (PCC/Rsp), the medial prefrontal cortex (MPFC), the inferior parietal lobe/angular gyrus (IPL/AG) and the medial temporal lobe (MTC) (Horn et al., 2014) as well as parts of the lateral temporal and lateral frontal cortex (Yeo et al., 2011). It is assumed to play a major role in self-referential thought processes (Buckner et al., 2008; Davey et al., 2016). Hence, these processes, in particular rumination, a reoccurring, rather abstract style of thinking about the past or shortcomings of the self, have been highlighted as a potential mechanism for the aberrant FC patterns within the DMN in depression (D. Rosenbaum et al., 2017). In their study on happiness Wayne et al. (2018) found higher resting state FC in the anterior and posterior DMN correlated with an inclination to ruminate and unhappiness. However, in a more recent study, the authors found increased as well as decreased DMN FC, depending on which measure of well-being was applied (Luo et al., 2017). Matching heterogeneity regarding increased and decreased DMN-activity has also been found in the literature on depression (Mulders et al., 2015; D. Rosenbaum et al., 2017; L. Wang et al., 2012).

Based on these findings of DMN FC variations at rest, we decided to apply a resting state paradigm and measure cortical FC at temporal/parietal areas of the brain with the help of functional near-infrared spectroscopy (fNIRS). As part of an ongoing project to study positive human neuroscience in more naturalistic contexts (including the perspective of measuring brain activity during whole-body movements) we used fNIRS because the method combines relatively high temporal resolution, mobile application, insensitivity to movement artefacts, low costs and easy assessment (Ehlis et al., 2014). Network-based statistics (NBS) were used to detect significant network differences in FC between the groups.

As the tendency to ruminate has shown to be relevant for differences in DMN FC, we included a trait and state measure to account for this. Furthermore, to also cover mental activity at the other side of the spectrum, we assessed the feeling of free flowing thoughts (mind-wandering) during the measurement. Mind-wandering in this sense, has been proposed as opposite mental state to rumination (D. Rosenbaum et al., 2017).

To control for general subjective experiences during the measurement, participants filled out an open-thought protocol (OTP) afterwards which consisted of a blank page to freely report all personal subjective experiences occurring during the measurement. To place findings within the broader context of clinical research we included a measure of depressive symptomatology. The overall goal of this study was to explore FC correlates of trait-like group differences in flourishing and Subjective Vitality with a focus on DMN activity and the mental processes of mind-wandering and rumination as potential explanatory variables.

2.2 Materials and Methods

Participants

Subjects were recruited using posters, flyers and the staff email distributor list of the University Hospital Tübingen. Among average healthy people, the recruitment information explicitly asked for participants who felt a lot of energy or a high degree of well-being in their daily life. Additionally, data from twelve healthy subjects, who were part of the control group of a clinical intervention trial (NCT02375308) on depression with a similar experimental procedure, were used in this study. This study was carried out in accordance with the recommendations of 'Ethical guidelines, Ethics Committee at the University Hospital and University of Tübingen' with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Ethics Committee at the University Hospital and University of Tübingen. Only healthy subjects without acute or chronic coronary heart disease (e.g., hypertonia), diabetes or a diagnosed psychological or neurological disorder were included. Using an online questionnaire, 62 individuals were prescreened with regard to the exclusion criteria and their level of flourishing and Subjective Vitality. 43 attended the laboratory session and provided data for the following analysis. Initially we planned on using *agreed* or *strongly agreed* on all items of one or both scales ($\geq$ 48 for flourishing, $\geq$ 36 for Subjective Vitality) as classification criteria for "high" in the respective outcome (Hone et al., 2014). However, over the recruiting process it proved more difficult to find participants meeting this criterion for Subjective Vitality compared to flourishing ($n_{SV} = 18$ vs. $n_{Fl} = 28$). To keep group sizes equal and since we were interested in exploring extreme group effects without hypothesis on the effect of a clear cut-off value, we used a median split approach (Farrington & Loeber, 2000) and assigned individuals with a score above the median ($m_{Fl} > 48$; $m_{SV} > 35$) to the respective "high" group. 25 individuals were grouped as regular-vital (regSV) and 18 as high-vital (highSV), 23 as regular-flourishing (regFl) and 20 as high-flourishing (highFl). Twelve of the highSV subjects (i.e. 66%) also belonged to the highFl group. The group characteristics are displayed in Table 2.1. In the overall sample, 14% of the participants held a middle school degree, 83.7% a high-school diploma (German Abitur) and 2.3% a university degree. 69.8% were currently enrolled as students, 27.9% indicated to work full-time. 65% of the participants were female. Both high score subgroups did not differ from their low score counterparts with regard to age (for SV $t_{41} = 0.99$, $p > 0.1$; for Fl $t_{41} = 0.95$, $p > 0.1$), sex ratio (for SV $\mathcal{X}_{21} = 0.22$, $p > 0.1$; for Fl $\mathcal{X}_{21} = 0$ $p > 0.1$) and level of education (for SV $\mathcal{X}_{22} = 0.99$, $p > 0.1$; for Fl $\mathcal{X}_{22} = 0.91$ $p > 0.1$).

Table 2.1. Sample and subgroup characteristics

	Regular-SV		High-SV			Regular-Fl		High-Fl		
	Mean	*SD*	Mean	*SD*	t/$\mathcal{X}^2$	Mean	*SD*	Mean	*SD*	t/$\mathcal{X}^2$
Scale	31.61	2.83	38.67	2.25		44.96	3.18	51.85	2.08	
Age (years)	27.5	6.55	30.72	12.46	$t_{(41)} = 0.99$ p > 0.1	31.00	11.36	27.96	9.56	$t_{41} = 0.95$ p > 0.1
Sex (f/m)	61.1%		68%		$\mathcal{X}_1^2 = 0.22$ p > 0.1	65%		65.2%		$\mathcal{X}_1^2 = 0$ p > 0.1
$N_{subgroup}$	25		18			23		20		
N_{highFl}	8		12		N_{highSV}	6		12		
N_{regFl}	17		6		N_{regSV}	17		8		

Overall sample (n = 43)	Mean	*SD*	Range	Kurtosis	Skewness	Cronbach's α	Retest r
Flourishing Scale	48.16	4.40	38-56	-0.407	-0.402	0.782	r_{35}= 0.84
Subjective Vitality Scale	34.58	4.35	25-42	-0.487	-0.128	0.785	r_{36} = 0.87

Note. Subgroups were derived using a median split (> 48 for High-Fl (high-flourishing), > 35 for High-SV (high-vital) subjects). Participants with median value were assigned to the lower subgroup to balance group size.

fNIRS

Hemodynamic changes were measured via fNIRS, an optical imaging method using light in the near-infrared spectrum to measure concentration changes of oxygenated and deoxygenated hemoglobin. The penetration depth and therefore spatial measurement depth of fNIRS is approximately 2–3 cm (Haeussinger et al., 2014). Importantly, fNIRS has been shown to be a useful and reliable device to measure FC (Deppermann et al., 2016; Lu et al., 2010; Mesquita et al., 2010; D. Rosenbaum et al., 2016; H. Zhang et al., 2010). We used a continuous wave, multichannel NIRS system (ETG-4000 Optical Topography System; Hitachi Medical Co., Japan) with a temporal resolution of 10 Hz. The distance between channels was 3cm. To measure parts of the DMN, we placed the probe set in the form of a rectangle over parietal areas covering the precuneus (Horn et al., 2014) with reference points Pz (Channel 16), T3 (Channel 43) and T4 (Channel 52), according to the 10-20 system (Jasper, 1958).The system consisted of 52 channels (supplementary figure 1). Channel positions with regard to Brodman areas were located using a neuro-navigation system on a volunteer's head (Figure 2.1).

Procedure

The resting state measurement was part of a larger study (NCT02375308) on the cortical correlates of depression and well-being. Results regarding the depressive subsample are reported elsewhere (D. Rosenbaum et al., 2017). For the purpose of this study, data was assessed during a 7-minute resting phase in which participants were asked to sit still with eyes closed, think of nothing in particular and let their

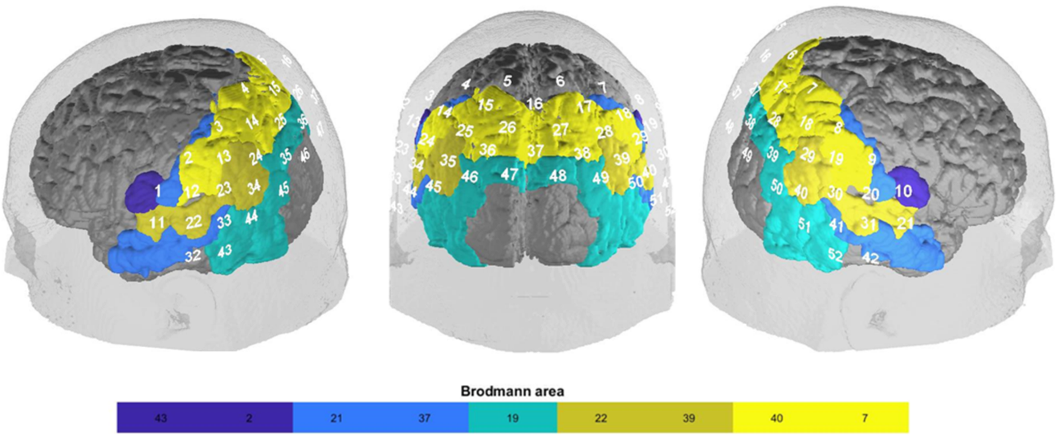

Figure 2.1. fNIRS-channel brain mapping (Brodman area) based on a neuro-navigational measurement in an exemplary volunteer: Somatosensory association cortex (BA 7; SAC; channel 4, 5, 6, 7, 15, 16, 17, 25, 26, 27, 28, 35, 36, 37), Supramarginal gyrus (BA 40; SupG; channel 2, 3, 8, 9, 12, 13, 18, 19, 23, 30), Angular gyrus (part of Wernicke's area; BA 39; AngG; channel 14,24, 29, 34, 39, 40, 45, 50), Superior temporal gyrus (BA 22; STG; channel 11, 21, 22, 31, 33, 41), Visual area 3 (BA 19; V3; channel 38, 46, 47, 48, 49), Fusiform gyrus (BA37; FusG; channel 43, 44, 51, 52), Middle temporal gyrus (BA 21; MTG; channel 32, 42), Primary somatosensory cortex (BA 2; PSC; channel 1,20), Subcentral area (BA43; SC; channel 10, 11).

thoughts flow. Since the participants had to complete other tasks as part of the overall study and RSFC has shown to be measurable reliably in short periods of time (Sakakibara et al., 2016; Zhao et al., 2016) we chosen 7-minute as a trade-off between data quality and economic demands.

Mind-activity measures

To assess thought processes and experiences during the measurement, directly after completion the subjects reported what they had done and experienced during measurement using 1) visual analogue scales (VAS) and 2) a blank page for a written OTP (D. Rosenbaum et al., 2017). For the VAS, subjects were asked to approximately rate on a scale from 0 to 100% how much time they had spent on ten different activities (D. Rosenbaum et al., 2017). The scales of mind-wandering and rumination during the measurement were analyzed for this study. The free written OTP was screened and categorized by two independent raters to assess qualitative measures of the process during resting state according to qualitative methods: The forms were first analyzed and categories of experiential content were set and defined until saturation was reached. Second, the most common categories were used to categorize self-report forms by two independent raters. Also, the raters evaluated the emotional tone (positive, negative, mixed, neutral) and level of arousal (calm, aroused) of the thought protocol. For the final analysis, the ratings of the two independent raters for each OTP were discussed if deviating and integrated in a final single rating.

Trait measures

Subjects were categorized based on their self-rating on scales of Subjective Vitality (Ryan & Frederick, 1997) and flourishing (Diener et al., 2010; Esch et al., 2012). Both scales where phrased to be answered with regard to life in general using a Likert-scale format (*strongly disagree – strongly agree*). The Subjective Vitality scale consists of six items to assess a person's self-perceived level of energy (e.g., Item 1: “I feel alive and vital”; Item 3: ”I have energy and spirit”) and alertness (e.g., Item 5: ”I nearly always feel alert and awake”) in daily life. Diener et al. (2010) proposed eight items to determine a person's level of flourishing. The scale covers aspects of self-perceived meaning and purpose (Item 1: ”I lead a purposeful and meaningful life”), engagement (Item 3: “I am engaged and interested in my daily activities”), competence (Item 5: “I am competent and capable in the activities that are important to me”), self-esteem (Item 6: “I am a good person and live a good life”), optimism (Item 7: “I am optimistic about my future”) and quality in relationships (Items 2, 4, 8 e.g., “My social relationships are supportive and rewarding”). Trait rumination was assessed using the subscale rumination of the ruminative response scale (RRS Nolen-Hoeksema & Morrow, 1991). To control for associations with depressive symptomatology we included the depression module of the Patient Health Questionnaire (PHQ-9 Kroenke et al., 2001).

Data Preprocessing

The data was processed and analyzed using MATLAB R2017b (MathWorks Inc, Natick, USA, RRID:SCR_001622). After preprocessing, the MATLAB NBS toolbox (Zalesky et al., 2010, RRID:SCR_002454), Wavelab850 toolbox (http://statweb.stanford.edu/ wavelab/) and BrainNetViewer toolbox (http://www.nitrc.org/projects/bnv; RRID:SCR_009446) (Xia et al., 2013) were used for analyzing and plotting results. Furthermore, SPSS (Version 24; RRID:SCR_002865) was used for data analysis. fNIRS data preprocessing included: bandpass filtering (0.1–0.01 Hz, FC differences were expected in this spectrum) to minimize high- and low-frequency noise, movement artefact reduction by correlation-based signal improvement (Brigadoi et al., 2014; Cui et al., 2010), as well as component-based removal of bite artefacts (ICA). For the resting state subjects were instructed to keep their heads as still as possible and refrain from clenching their teeth. Afterwards, all signals were visually inspected which revealed noisy channels after the described preprocessing in seven subjects. In these cases, channels were interpolated from surrounding channels. Three (one subject) or one channel (six subjects) had to be interpolated. Since FC can be significantly influenced by global signal changes, e.g. low frequency blood pressure oscillations (Mesquita et al., 2010), a global signal reduction was performed with a spatial Gaussian Kernel filter (X. Zhang et al., 2016) with a standard deviation of $\sigma = 50$. No short distance channels were used. After preprocessing, FC-coefficients were computed for each participant using pairwise correlation between all channel's signal time courses. The values were then transformed via Fishers r-to-z-transformation (Silver & Dunlap, 1987).

Network-based Statistics (NBS)

Subsequent FC-differences between the flourishing and the Subjective Vitality subgroups were investigated with Network-based Statistics (Zalesky et al., 2010). NBS is a statistical method that uses massive univariate testing of a contrast on connectivity matrices, and clusters connections that exceed a significance threshold using a breadth first search. The significance of the extracted cluster is then tested using permutation tests. The resulting p-values represent the likelihood to attain a cluster, similar or larger in the number of connected edges under the assumption of random group assignment of the individual scores in the sample at hand. Settings for NBS were set as follows: statistical threshold for massive univariate testing was set at $t = 3.1$, significance level for permutation tests $\alpha = 0.05$, permutations = 5000, component size = 'extent'. We estimated confidence intervals for the computed p-values of the permutation tests parametrically following Zalesky et al. (2010).

Analysis Procedure

The following analysis was performed on the data: After the computation of FC measures, network-based statistics (NBS) were used to identify network-differences in FC between the highFl (score > 48) and the regFl group as well as between the highSV (score > 35) and the regSV group. Group differences were calculated using independent t-tests and chi-squared tests for the VAS, trait rumination,the OTP and depressive symptomatology. Whenever stated, significance levels for these tests were adjusted for multiple comparisons using the Bonferroni correction method. Significant group differences in mind-wandering, rumination and depressive symptomatology were used as covariates in the NBS models to test their role as explanatory variables for differences in FC patterns. In case of a significant influence of the covariate on the NBS its influence was further explored via the examination of correlations between the covariate and the significant network connections. To further explore the relation between Subjective Vitality and flourishing, we calculated NBS for one variable using the other as covariate and calculated correlations between the covariate and the significant network connections of the hub nodes in each network. Eventually, hub nodes (≥ 3 edges) of the significant networks were used as seed regions and the group comparisons in network connectivity strength were plotted. The fNIRS raw data as well as the respective code script and SPSS file are available under https://doi.org/10.17026/dans-zym-vewk

2.3 Results

Flourishing

The NBS yielded a single higher connected network for the highFl group, comprising 11 functional connections at threshold $t = 3.1$ ($p = .036 \pm .0053$). The derived network consisted of 10 nodes with 11 edges (Table 2.2). Nodes were classified as hub nodes if they had more than three edges. The network centered around two hub nodes in the left middle temporal (MTG) and the left fusiform gyrus (FusG), spreading onto bilateral parietal areas of the default mode network (Figure 2.2 A), bilateral parts of the somatosensory association cortex (SAC) and visual area (V3). The right angular (AnG) and supramarginal gyrus (SuG) were part of the network in the right hemisphere. Further analysis revealed that flourishing correlated significantly positive with all except two connections in the network ($p < .10$). All correlations are displayed in Table 2.3. The differences in FC between regFl and highFl participants are displayed in Figure 2.3 using the two hub nodes left MTG (A) and left FusG (B) as seed channels.

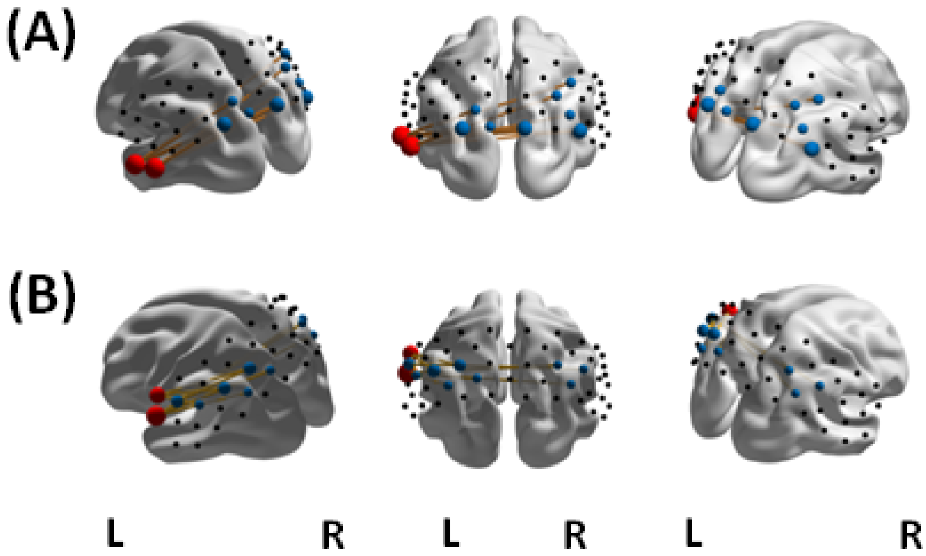

Figure 2.2. Significant NBS network at t= 3.1 for FC in the **(A)** high-flourishing group compared to the regular-flourishing group with hub nodes (red) at left MTG and left FusG, other network nodes (blue) and edges (yellow). The significant NBS network at t = 3.1 for FC in the high-vital group compared to the regular-vital group with hub nodes (red) at left SC and left PSC is displayed in **(B)**.

Table 2.2. Degrees of the significant network differences between high-flourishing and regular-flourishing subjects ($t = 3.1$) and high- and regular-vital Subjects ($t = 3.1$)

Channel	Region	Flourishing ($t = 3.1$) Degree	Subjective Vitality ($t = 3.1$) Degree
1	PSC (left)		**3**
11	SC/STG (left)		**5**
12	SupG (left)		2
18	SupG (right)	1	
23	SupG (left)		1
24	AngG (left)		2
25	SAC (left)		2
28	SAC (right)	1	1
29	AngG (right)		1
32	MTG (left)	**6**	
35	SAC (left)		1
36	SAC (left)	1	1
39	AngG (right)	1	1
43	FusG (left)	**5**	
46	V3 (left)	2	
47	V3 (left)	1	
48	V3 (right)	2	
50	AngG (right)	2	
Nodes		10	11
Edges		11	10
p-value		.036 ± .0053	.046 ± .0059

Note. Only channels of the significant networks are presented. PSC - primary somatosensory cortex; SC - subcentral area/secondary somatosensory cortex; SupG - supramarginal gyrus; AnG - angular gyrus; SAC - somatosensory association cortex; MTG - middle temporal gyrus; FusG - fusiform gyrus; V3 - visual area. Hub nodes marked in bold.

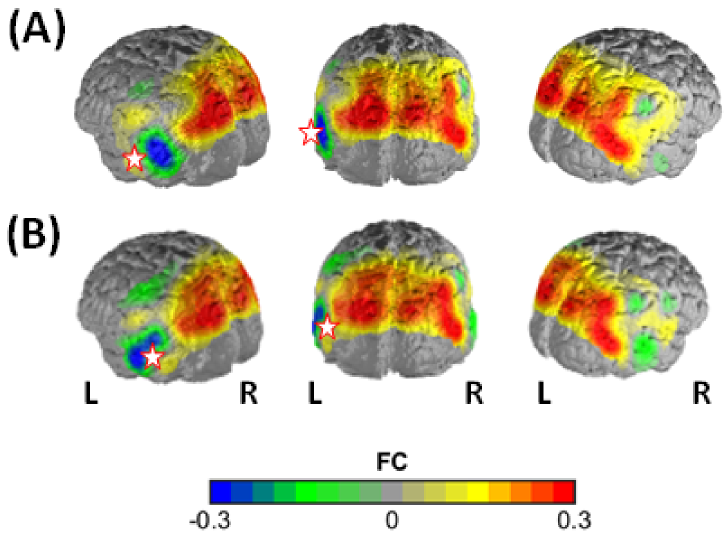

Figure 2.3. Difference in FC between the high-flourishing and regular-flourishing group with **(A)** channel 32 (lMTG) and **(B)** channel 43 (lFusG) as seed regions. Warm colors indicate higher FC with seed in high-flourishers vs. regular-flourishers.

Table 2.3. *P*-Values of the significantly stronger connected network channels in the flourishing network and correlates with flourishing, Subjective Vitality, mind-wandering, trait rumination, and depression

Hub nodes (seed)		**t = 3.1**	**Flourishing**		**Subjective Vitality**		**Mind-wandering**		**Trait rumination**		**Depression**	
		p-value	r	p	r	p	r	p	r	p	r	p
Flourishing network												
lMTG (CH 32)	rSupG (Ch 18)	.002	.39*	.01	.13	.387	.30	.05	-.20	.204	-.31*	.041
	lSAC (CH 36)	.001	.26	.095	.21	.172	.29	.058	-.28	.071	-.36*	.018
	lV3 (Ch 46)	.001	.26	.096	.16	.303	.35*	.023	-.33*	.029	-.20	.203
	IV3 (Ch 47)	.002	.22	.158	.18	.252	.39*	.009	-.30	.05	-.27	.077
	rV3 (Ch 48)	.002	.29	.062	.18	.241	.44*	.003	-.32*	.036	-.31*	.04
	rAngG (Ch 50)	.003	.21	.174	.20	.195	.26	.096	-.26	.089	-.21	.166
lFusG (Ch 43)	rSAC (Ch 28)	.003	.36*	.018	.17	.284	.22	.146	-.35*	.021	-.38*	.012
	rAngG (Ch 39)	.002	.31*	.04	.12	.451	.19	.231	-.28	.065	-.34*	.028
	lV3 (Ch 46)	.002	.29	.06	.17	.278	.30	.051	-.42*	.005	-.30*	.047
	rV3 (Ch 48)	.001	.30	.053	.15	.34	.43*	.004	-.37*	.014	-.35*	.021
	rAngG (Ch 50)	.003	.26	.086	.26	.086	.16	.305	-.33*	.032	-.27	.074

Note. All variables were used as covariates in a follow-up NBS analysos of flourishing $^*p < .05$; the p-value corrected for multiple comparison was p < .0045.

Subjective Vitality

In the comparison of the highSV and the regSV group, the NBS analysis yielded a significantly higher connected network for the highSV group comprising 10 functional connections at threshold $t = 3.1$ ($p = .046 \pm .0059$). The network consisted of 11 nodes and 10 edges (Table 2.2). The major hub node was located in an overlapping area of left subcentral area (SC) and superior temporal gyrus, connecting to nodes in the bilateral SAC and the bilateral AnG. The second most connected node within the primary somatosensory cortex stretched to left SupG, left AnG and left SAC (Figure 2.2 B). The network did not reach significance ($p < .05$) at any other threshold, however different thresholds returned p-values close to the level of significance ($t = 2.8$, $p = .0721$, $t = 3.0$, $p = .0546$; $t = 3.2$, $p = .0618$; $t = 3.3$, $p = .0552$). In depth analysis revealed that Subjective Vitality correlated positively with all connections in the network ($p < .05$, Table 2.4). The differences in FC between regSV and highSV participants are displayed in Figure 2.4 using the two hub nodes left PSC and left SC as seed channels.

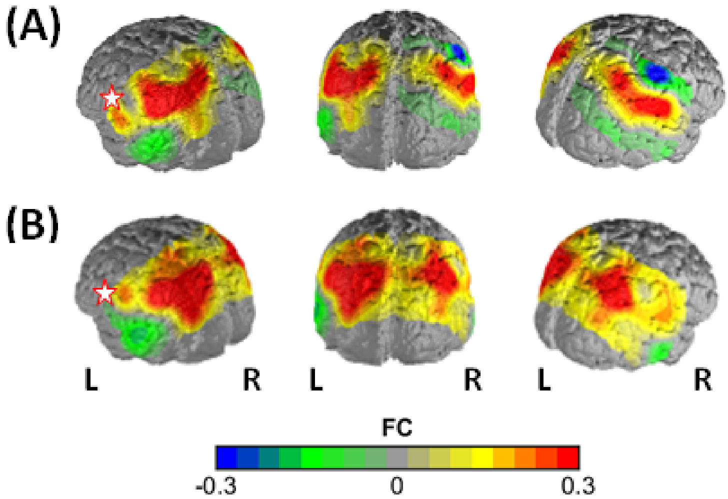

Figure 2.4. Difference in FC between the high-vital and the regular-vital group with **(A)** channel 1 (PSC) and **(B)** channel 11 (lSC) as seed regions. Warm colors indicate higher FC with seed in high-vital vs. regular-vital participants.

Table 2.4. *P*-Values of the significantly stronger connected network channels in the Subjective Vitality network and correlates with flourishing, Subjective Vitality, mind-wandering, trait Rumination, and depression

Hub nodes (seed)		$t = 3.1$	**Flourishing**		**Subjective Vitality**		**Mind-wandering**		**Trait rumination**		**Depression**	
		p-value	r	p	r	p	r	p	r	p	r	p
Subjective Vitality network												
lSC/STG (CH 11)	lAngG (Ch 24)	.002	.17	.261	.33*	.033	-.03	.856	.02	.916	-.16	.30
	lSAC (CH 28)	.001	.24	.124	.33*	.031	-.02	.916	.06	.682	-.02	.873
	lSAC (Ch 35)	.003	.24	.120	.36*	.018	.13	.387	.05	.77	-.03	.826
	lSAC (Ch 36)	.001	.14	.366	.41*	.006	-.06	.678	.17	.277	-.04	.811
	rAngG (Ch 39)	.003	.20	.199	.33*	.03	-.095	.546	.11	.497	.05	.735
lPSC (Ch 1)	lSupG (Ch 23)	.001	.20	.19	.35*	.023	-.17	.277	-.10	.52	-.11	.491
	lAngG (Ch 24)	< .001	.15	.345	.34*	.026	-.21	.17	-.09	.553	-.08	.63
	lSAC (Ch 25)	.002	.18	.258	.40*	.008	-.18	.234	-.05	.743	-.03	.848
SupG (Ch 12)	lSAC (Ch 25)	.003	.08	.623	.34*	.027	-.25	.102	.06	.719	.08	.588
	rAngG (Ch 29)	.006	.24	.121	.18	.241	-.21	.183	-.17	.261	-.05	.741

Note. All variables were used as covariates in a follow-up NBS analysos of Subjective Vitality $^*p < .05$; the p-value corrected for multiple comparison was p < .0045.

Covariate Networks and the Relation between Flourishing and Subjective Vitality

Subjective Vitality was positively correlated with flourishing (r = .63, p < .001). When using Subjective Vitality as a covariate in the NBS procedure for flourishing, the significant network difference between the flourishing groups dissolved. However, in depth analysis of the correlations between Subjective Vitality and the network connections in the flourishing network yielded only one marginally significant correlation with the connection between lFusG and rAngG (r = .26, p = .086). All correlations are displayed in Table 2.3. Entering flourishing as a covariate into the NBS analysis of Subjective Vitality, yielded a significant network comprising 11 nodes and 11 edges at t = 3.1 (p = .044 ± .0058). In contrast to the original vitality network, this network remained significant at different thresholds. At t = 2.3 a significant network resulted comprising 29 nodes and 67 edges (p = .040 ± .0055). At t = 2.7 the network decreased to 21 nodes and 35 edges (p = .028 ± .0047). Flourishing showed no significant correlations with any of the connections of the Subjective Vitality network (all p > .10; Table 2.4).

Rumination, Mind-wandering, the OTP and Depressive Symptomatology

HighFl participants reported significantly more mind-wandering than regFl participants ($t_{32.2}$ = 4.338, p < .001, d = 1.296), significantly less trait rumination (t_{41} = 3.196, p = .003, d = 0.99) and significantly less depressive symptomatology ($t_{34.5}$ = 2.520, p = .017, d = 0.75); no significant difference between groups was found for state-rumination. The highSV and the regSV group did not differ significantly on mind-wandering, depressive symptomatology, state or trait rumination. Both high-score groups did not differ from their regular counter parts with respect to any category of the OTP. The categories derived for the OTP and content classification percentages are presented in Appendix A (Supplementary Table A.1). The only exception was the extent of thinking about the measurement for the flourishing groups (25% of regFl vs. 5% of highFl; $\mathcal{X}^2_1$= 7.257, p < .004 corrected for multiple comparison, OR = 8.25). Also, no group differences were found for emotional tone and experienced arousal.

Rumination, Mind-wandering and Depressive Symptomatology as Covariates in the NBS

Because trait rumination, mind-wandering and depressive symptomatology differed significantly between the highFl and the regFl group we conducted further analysis and used all three variables as covariates in a repeated NBS analysis of flourishing.

Using the degree of mind-wandering in the NBS for the flourishing groups as a covariate rendered the network insignificant. A closer examination of the relation between mind-wandering and FC within the flourishing network, when using the hub node in the left MTG as a seed region, revealed significantly positive correlations for six network connections ($p < .10$). However, only the relation with the right visual area remained significant after correction for multiple comparisons ($r = .44$, $p < .0045$). Using the second hub node within left FusG as a seed yielded positive correlations for the connection with the left visual area ($r = .30$, $p = .051$) and right visual area ($r = .43$, $p = .004$). The latter remained significant after correction for multiple comparisons ($r = .43$, $p < .0045$). All correlations are displayed in Table 2.3.

When trait rumination was entered as a covariate, also no significant network resulted as a difference between groups. Further analysis revealed FC within the flourishing network to be negatively correlated with trait rumination. When using the left MTG as a seed, significant negative correlations were found for FC with left (r = -.33, $p = .029$) and right visual area (r = -.32, $p = .036$). The associations with left SAC (r = -.28, $p = .071$) and right angular gyrus (r = -0.26, $p = .089$) pointed towards a significant correlation ($p > .10$). No correlation survived correction for multiple comparisons ($p > .0045$). When taking the left fusiform gyrus as a seed region correlations between trait rumination and FC with bilateral visual area (-0.42 < r < -0.37, .005 < p < .01) right AnG (r = -.33, $p = .032$) and rSAC (r = -.35, p = .021) turned out significant. No correlation remained significant after correction for multiple comparisons. All correlations are displayed in Table 2.3.

Using depressive symptomatology as a covariate in the NBS yielded no significant connectivity network difference between the highFl and the regFl group. Further correlational analysis revealed negative correlations between depression and the connectivity strength between lMTG and rSupG (r = -.31, $p = .041$), lSAC (r = -.36, $p = .018$) and rV3 (r = -.31, $p = .041$). Furthermore, depressive symptomatology correlated negatively with the connectivity strength between lFusG and rSAC (r = -.37, $p = .012$), rAngG (r = -.34, $p = .028$), lV3 (r = -.30, $p = .047$) and rV3 (r = -.35, $p = .021$). No correlation surved correction for multiple comparison ($p <$ .0045).

In case of the NBS for Subject Vitality, mind-wandering as a covariate led to a decrease of the original network comprising seven nodes with six edges at $t = 3.2$ ($p = .047 \pm .0060$). The original network remained stable when trait rumination was added as a covariate in the NBS ($p = .049 \pm .0061$). Adding symptoms of depression as covariate lead to no significant group differences in connectivity strength at threshold of $t = 3.1$. However, a marginally significant difference resulted at threshold $t = 2.9$ ($p = .0902 \pm .0081$). All correlations of the covariates with the Subjective Vitality network are displayed in Table 2.4.

2.4 Discussion

The goal of this study was to investigate associations of cortical functional connectivity at rest with two widely used indicators of well-being – flourishing and Subjective Vitality. For people high in flourishing, we found significantly increased FC within a network comprising parts of the default mode network (right angular gyrus, right supramarginal gyrus, left middle temporal gyrus), bilateral somatosensory and visual cortex, and left fusiform gyrus. For high-vital participants, we found a network of significantly increased FC related to the DMN (bilateral angular gyrus, left supramarginal gyrus, left superior temporal gyrus) and nodes in bilateral somatosensory, left primary and secondary somatosensory cortex. The inclusion of either mind-wandering, trait rumination or depression as covariate in the NBS nullified the difference in FC between the flourishing groups. In comparison, the vitality network remained, when including mind-wandering or trait rumination as a covariate in the NBS. Depressive symptomatology as covariate led to a marginally significant difference at a lower threshold.

DMN

Our results add to prior findings of the association between changes in DMN FC and trait indicators of well-being (Luo et al., 2017; Wayne et al., 2018). However, depending on the measure of well-being and the specific area of the DMN, the authors reported heterogeneous findings regarding the increase and decrease of FC. In our study, which was limited to parietal and temporal cortex areas, we observed increased FC for areas that included the bilateral inferior parietal lobe (angular gyrus/supramarginal gyrus) and left lateral temporal areas.

Flourishing

The network of increased FC within the highFl group centered around two hub nodes in the left middle temporal gyrus and the left fusiform gyrus. As part of the DMN, the MTG has been associated with the provision of memory content in the process of spontaneous thought generation (Smallwood et al., 2016) but also social information processing in general (Alcalá-López et al., 2017). Behavioral research shows that the DMN related activity of mind-wandering is crucial for the navigation of the social world (Poerio & Smallwood, 2016) and in turn, social day-dreaming is being associated with increased feelings of love, connectedness and happiness (Poerio et al., 2015). We believe this is a potential dynamic behind the results in this study as a major factor in the selection of individuals as high-flourishing was the reported quality of their social relationships. HighFl participants showed higher ratings of social commitment for others and perceived support and respect in their relationships (three out of seven items).

Our findings of increased FC in social- and DMN-related brain areas in highFl individuals and the role of mind-wandering indicate a link between three different lines of research: The *social brain* (Alcalá-López et al., 2017; Tan et al., 2014), DMN-related spontaneous thought activity (Smallwood et al., 2016) and the importance of social factors for well-being (Diener & Seligman, 2002; Kafetsios & Sideridis, 2006; Sánchez-Álvarez et al., 2016). The fusiform gyrus as second hub node in the flourishing network and its role in face recognition (Kanwisher & Yovel, 2006) with relevance for social cognition and emotional intelligence (Takeuchi et al., 2011; Takeuchi et al., 2013) lent further support to this hypothesis. The co-appearance of left MTG and fusiform gyrus in our findings is also in line with a PET study by Volkow et al. (2011) which found positive emotionality, a construct composed of well-being, achievement/motivation, social potency and social closeness, to be positively associated with glucose metabolism in the left middle temporal gyrus and fusiform gyrus.

Overall, our results for flourishing and brain activity are consistent with studies that suggest a link between the processing of social cues, DMN activity and increased levels of well-being. At the same time they provide support for a mechanism underlying the prominent broaden-and built theory of positive emotion (Fredrickson, 2001). Multiple behavioral studies have supported the claim that positive emotion broaden our scope of attention and foster a state of learning (Fredrickson, 2013); our findings indicate an extension to the neurophysiological level via the link of differences in DMN related FC, mind-wandering and trait levels of flourishing.

Subjective Vitality

The two hub nodes in the vitality network were located in the left primary and secondary somatosensory cortex (Eickhoff et al., 2006) overlapping with posterior left superior temporal gyrus. Individuals high in trait Subjective Vitality report prolonged feelings of increased aliveness and energy, which is in line with findings of a connection between primary somatosensory cortex and arousal and attention related areas of the brain (Gobbelé et al., 2000; Jang et al., 2014). A higher level of perceived energy can also be achieved via anodal transcranial direct current stimulation (tDCS) of the bilateral primary somatosensory cortex (Tecchio et al., 2014). The posterior superior temporal gyrus has been linked to DMN activity (J. Wang et al., 2015) whereas the secondary somatosensory cortex has been associated with the unconscious representation of feelings and peripheral-physiological activity (Anders, Birbaumer, et al., 2004; Anders, Lotze, et al., 2004). The frequent experience of elated, positive states associated with physiological arousal in highSV individuals (Ryan & Bernstein, 2004) is in line with these findings. On a higher level, primary somatosensory cortex and somato-associative cortex play a role in the feeling of ownership and identification with one's own body (Aspell et al., 2012; Blanke, 2012). This form of body-connection, in turn, is positively associated with physical activity (Babic et al., 2014). Results from this study sample (reported elsewhere) suggest that the highSV group (M = 8.34, SD = 4.23) spends significantly more hours on physical activity per week (t_{32} = 3.540, p = .001) than the regSV group (M = 3.72, SD = 3.37). However, this difference does not exist for highFl and regFl individuals (t_{32} = 0.28, p = .781).

The assumption that highSV individuals may be more prone to body-related self-processing relates to the DMN literature as Treserras et al. (2009) found that sensorimotor networks become coupled with DMN networks when preparing for movement or activity; a state which, according to the authors, can last over longer periods of time and may be one explanation for the findings regarding Subjective Vitality in this study. In contrast to flourishing, entering mind-wandering as covariate only decreased the size of the FC network difference between highSV and regSV participants. This is consistent with the fact that part of the vitality network shows DMN overlap whereas the major hub nodes in the primary and secondary somatosensory cortex are not considered part of the DMN.

Flourishing and Subjective Vitality

Despite the conceptual overlap of Subjective Vitality and flourishing, the body as a stage for subjective experience (Damasio et al., 2000) may be more prominent in highSV individuals. HighFl individuals on the other hand, are a selection of people with strong positive cognitive evaluations of life (e.g., the self, social relationships, the future). In their joint NBS analysis flourishing as a covariate stabilized the vitality network, whereas Subjective Vitality as a covariate dissolved the flourishing network. We speculate that adding cognitive DMN related components of flourishing on top of a body-related vitality core component increases the network, whereas taking the body-related core away removes variance of a more fundamental component that is nevertheless central to flourishing. Adding to the argument of a different role of cognition in the two well-being measures is the finding that habitual (rumination) and spontaneous (mind-wandering) thought processes explained main shares of variance in FC between the flourishing but not the Subjective Vitality groups. State rumination did not significantly differ between groups and was not used further as covariate in the analysis. On the one hand, a mere resting state procedure may not be an adequate measure to assess healthy people's spontaneous tendency to ruminate (D. Rosenbaum et al., 2017), on the other hand, the experience of spontaneous flowing thoughts may just be of higher discriminative power regarding the extent of well-being in non-clinical samples.

Overall, we speculate the high correlation between flourishing and Subjective Vitality and their distinct relation to states of mind indicate essential overlap between the two constructs with potential differences in higher order brain processes (Kringelbach & Berridge, 2017).

Flourishing, Subjective Vitality and symptoms of depression

Of further interest is the fact that in this study we found depressive symptomatology to be negatively correlated with flourishing on a behavioral and neurophysiological level. The findings support the notion of an anti-relation between flourishing and mental illness (Huppert & So, 2013). For Subjective Vitality, the inclusion of depressive symptoms in the NBS analysis weakened the group differences on a neurophysiological level and no relation was found on a behavioral level. Depression showed no significant correlation with any of the significant network relations in the Subjective Vitality network which speaks to the fact that the NBS result may be more of a power problem. If so, the findings are in line with research that shows well-being/positive valence as a distinct phenomenon which goes beyond the mere opposite of malicious states (Cuthbert & Insel, 2013; Keyes, 2002). Among a more differentiated diagnostic, these findings may be relevant for the creation and effect of interventions where improvement and prevention of states of illness may demand different foci. Further research on the neurophysiology of positive states and traits could help to illuminate what is needed for each segment.

Limitations

One major limitation of this study was the restriction on parietal cortical areas of the DMN. Due to its usability and robustness against artefacts, fNIRS is a promising method to study brain activity and spontaneous thought processes in naturalistic contexts. However, this comes at the cost of limited insight into the activity of deeper-lying brain structures and whole brain activity. In case of this study, no conclusions can be drawn about medial and frontal sub-components of the DMN. Secondly, we used network-based statistics to identify significant differences in brain activation between groups. This approach allows for an interpretation on a network-level; conclusions on the role of single nodes have to be taken with care. Differences in DMN activity during rest have been related to group differences as well as various types of self-generated thought. However, due to the lack of experimental control during the resting state, the interpretability of ongoing mind and brain processes within the participant is limited. We tried to control for this via the collection of OTP data from each participant after the measurement. However, we did not find any significant difference with regard to the content and emotional tone reported by the participants in the different groups. Meyer et al. (2015) reported changes in brain activity following imagined relieve of physical pain which did not display in the self-report of participants following their measurement. This adds to our findings, as the role of subconscious processes and lack of information about the ongoing experience of the participant are two major limitations that need to be considered in the interpretation of our results. A further constraint in this study was the limitation of statistical power to detect medium and small effect sizes due to the modest sample size. In the case of the NBS for Subjective Vitality and the in-depth analysis of covariates a number of results were significant only at the level of $\alpha = .10$ and often did not survive correction for multiple comparison. One major strength of NBS is the increase in statistical power (Zalesky et al., 2010) that comes at the cost of limited interpretational power of single network connections. We therefor believe, the results of this study should be considered a starting ground that needs to be tested and extended in future studies.

2.5 Conclusion

In the well-being literature, conceptual distinctions have been made between eudaimonic and hedonic components of well-being (Peterson et al., 2005; Ryan & Deci, 2001). Others have separated cognitive from affective or global from specific aspects of subjective well-being (Diener, 1984; Diener et al., 1999). Flourishing has evolved as a complex construct in response to the diversity in symptomatology of psychological disorders. Subjective Vitality on the other hand specifically addresses the link between the subjective experience and organismic processes rooted in the human body. Hence, both constructs are distinct from other constructs used in the existing well-being literature. A neurophysiological framework to integrate the different concepts is still lacking. Our results add to the existing literature by showing distinct cortical FC correlates of flourishing and Subjective Vitality in the brain at rest. This may serve the purpose of further unraveling the neurophysiological correlates of the good life.

Chapter 3

State Subjective Vitality and Heart Rate Variability

Abstract

Mind-body exercises such as Yoga or Qi Gong have demonstrated a wide range of health benefits and hold great promise for employment in clinical practice. However, the specific psychophysiological mechanism underlying these effects is less well researched. To close this gap, we tracked acute changes in heart rate variability and subjective state over a common form of mind-body exercise (Qi Gong). 42 Qi Gong practitioners in China and Germany were assessed in a within-subject design to explore general and specific patterns of psychophysiological regulation during Qi Gong compared to a resting control condition. Over the course of the exercise, all participants showed an increase in Subjective Vitality linked to a general pattern of moderate physiological activation: Parameters associated with vagal modulation significantly decreased compared to a relaxing control condition. Simultaneously, subjects displayed a micro-pattern of slow-paced up-and down regulation in autonomic nervous system activity. The rhythm mirrored specific activation patterns within the exercise and led to a significant raise in cardiac coherence. No significant differences pre-post the exercise were observed. Significant associations between Qi Gong specific beliefs, age, cultural background and experiential and physiological measures demonstrated the complexity of mind-body exercises as multicomponent interventions. Overall, this study highlighs moderate activation and slow-paced rhythmic physiological regulation, leading to an increase in Subjective Vitality during Qi Gong as potential psychophysiological mechanism underlying the health benefits of mind-body exercise.[3]

[3]Goldbeck, F., Xie,Y.L., Hautzinger, M., Fallgatter, A.J., Sudeck, G. and Ehlis A.-C. (submitted). Relaxation or regulation - the psychophysiological mechanism underlying mind-body exercise.

3.1 Introduction

Qi Gong, a form of body-mind exercise (Y. T. Wang et al., 2017) from Traditional Chinese Medicine has shown promising effects in the alleviation of some of society's most debilitating conditions (Bai et al., 2015; Hartley et al., 2015; Meng et al., 2018; Wayne et al., 2018; Zou et al., 2018). Risk factors such as stress (C.-W. Wang et al., 2014) and sleep quality (F. Wang et al., 2016) are responsive to regular Qi Gong practice, and evidence about its long-term benefits on a physiological level is beginning to accumulate (Bower & Irwin, 2016; Buric et al., 2017; Meng et al., 2018; Morgan et al., 2014; Ng & Tsang, 2009). However, equivocal evidence still exists regarding the acute physiological and subjective experiential effect of Qi Gong – a gap we aimed to address in this study.

Qi Gong and Heart Rate Variability

From the perspective of TCM theory, the state induced via Qi Gong arises from optimal psychophysiological regulation (Bower & Irwin, 2016; Greten, 2007; Ng & Tsang, 2009). One prominent indicator reflecting psychological and physiological influences on the autonomic nervous system is the variability of adjacent heart beat intervals (HRV Shaffer & Ginsberg, 2017). Dysregulation of the ANS indexed by aberrant changes in HRV has been linked to various diseases and associated risk factors (Järvelin-Pasanen et al., 2018; Kemp et al., 2017; Stuckey et al., 2014). Concerning Qi Gong's influence on HRV, the majority of studies has looked at changes of resting state HRV in Qi Gong beginners following training protocols of 12–24 weeks (M.-Y. Chang, 2015; Kuan et al., 2012; Lee et al., 2018; M. Li et al., 2015; R. Li et al., 2014; Ying et al., 2019). Findings in these studies have been equivocal. Regarding acute changes of HRV parameters, Lin et al. (2018) found no acute changes in the low-frequency (LF) and high-frequency power following 18-Forms Tai Chi International Qi Gong. However, the author's reported a significant decrease in the LF- and increase in the HF-spectrum towards the end of the practice. Baduanjin is a widely practiced standard form of Qi Gong and increasingly used in research (Zou et al., 2017); however, the acute influence of Baduanjin on HRV has not been tested. To assess the acute influence of Qi Gong on HRV, we assessed standard HRV parameters in the time and frequency domain (Shaffer & Ginsberg, 2017; Shaffer et al., 2014) before, during and following two bouts of Baduanjin.

A specific parameter associated with increased well-being and psychophysiological balance is cardiac coherence (McCraty & Childre, 2010; McCraty & Zayas, 2014; Tiller et al., 1996). Earlier findings mentioned Qi Gong as a promising candidate to induce a state of coherence (Tiller et al., 1996), however, no study has empirically tested this assumption. To assess Qi Gong's quality as a mind-body exercise, we included cardiac coherence, besides standard parameters of HRV, as a potential correlate for the specific state achieved through the adjustment of mind, body and breath in Qi Gong (Chen & Liu, 2010).

Qi Gong and Subjective State

Qi Gong directly translates as "vital energy cultivation" (气: vital energy; 工: work/cultivation). In western psychology, vitality on an experiential level has been adopted as Subjective Vitality, a dynamic aspect of well-being marked by the subjective experience of energy and aliveness (Peterson & Seligman, 2004; Ryan & Frederick, 1997). Subjective Vitality has been linked to regulative capacity of the self (Muraven et al., 2008) and described as distinct from relaxed "non-activated positive states such as happiness, satisfaction, and contentment" (Nix et al., 1999; Ryan, Weinstein, et al., 2010, p.159). Hence, Subjective Vitality was used to capture a non-relaxed state of *eutonic calmness* (Payne & Crane-Godreau, 2013) associated with optimal regulation during Qi Gong .

To characterize the state in more detail, we complimented the measure of Subjective Vitality with sub-components relevant to the distinction between *hypotonic relaxation* and eutonic calmness (Payne & Crane-Godreau, 2013). R. Thayer (2001) used the term *calm energy* to describe a state simultaneously high in calmness and in energetic arousal in a two-dimensional space. To mirror these aspects, we assessed perceived calmness and body activation in the present study. Based on Larkey's 2009 definition of Qi Gong as *meditative movement*, we expected further state characteristics of increase in attentional focus, a heightened body awareness and an increase in pleasant body sensations.

Covariates – the Influence of Culture, Belief, Experience and Age

A unique feature of the common mind-body exercises (i.e., Yoga, Taiji, Qi Gong) is the pervasive influence of their respective cultural background (e.g., language, beliefs, rituals, practice habits, assumed stages of development etc.). In comparison to other forms of exercise, this makes body- mind exercise a multicomponent intervention with inherent challenges to the examination within a classical randomized control trial design (Wayne & Kaptchuk, 2008a, 2008b). To approach this problem from a different angle, we applied a within subject design and explored the influence of four covariates potentially relevant to the acute effect of Qi Gong: To examine the influence of cultural background, we recruited participants from an incongruent (Germany) and a congruent cultural background (China) and reexamined overall effects in the two national subsamples. For the influence of Qi Gong specific beliefs, participants filled out a Qi Gong specific self-report measure (method section) developed for this study. Different levels of mastery in the respective exercise are assumed to enable different types of inner experiences and physiological response in practitioners (Chen & Liu, 2010; T. Liu, 2016). Hence, we recruited practitioners with varying amounts of experience and used “years of Qi Gong experience” as a covariate. Age was used as a covariate due to the predominance of interest in Qi Gong among older populations and the demonstrated influence of age on HRV (Shaffer & Ginsberg, 2017). In applying these covariates and the respective design, we aimed to complement findings from randomized control trials and disentangle global from specific effects characteristic for the practice of Qi Gong.

The Present Study

The overall goal of this study was to explore the psychophysiological mechanism underlying mind-body exercise via the examination of acute changes in subjective state and heart rate variability during rest and a standard moving Qi Gong exercise. We assumed that Qi Gong would increase levels of Subjective Vitality and related subjective indicators to a state of increased perceived body activation and calmness, with a concurrent high degree of body awareness and attentional focus that would feel pleasurable. Based on the equivocal results of the literature, an exploratory approach was used with regard to the impact of Qi Gong on HRV parameters. The covariates cultural background, beliefs, experience and age were controlled in order to gain a better understanding of potentially underlying mechanisms in the short- and long-term effects of Qi Gong practice.

3.2 Materials and Methods

Sample

Qi Gong practitioners were recruited in mainland China ($n = 21$) and in Germany ($n = 21$). The Chinese group consisted of former and temporary students at the Shanghai University of Sport. The German sample consisted of amateur practitioners and coaches from various Qi Gong training locations in south Germany. The bi-national protocol was approved by the Ethics Committee at the University Hospital and University of Tübingen and all subjects gave written informed consent in their respective mother language in accordance with the Declaration of Helsinki. The inclusion criteria were: free of current medication, no cardiovascular disease or diabetes, ability to perform the Qi Gong exercise Baduanjin. The basic characteristics of the overall sample and the two national subgroups are described in Table 3.1. An in-depth analysis of the two subgroups can be found in Appendix B.

Table 3.1. Demographic variables and descriptive statistics for the overall and national sub-samples

	Overall sample $N = 42$		**Chinese sample** $n = 21$		**German sample** $n = 21$		**Test statistics** (comparison of national subsamples)
	M	*SD*	*M*	*SD*	*M*	*SD*	**t**/$\mathcal{X}^2$
Age	42.60	18.30	28.81	11.56	56.38	12.4	$t_{40} = 7.45$ $p < .001$
Sex (f/m)	67.4%		61.9%		76.2%		$X_1^2 = 1.00$ $p > 0.1$
	32.6%		38.1%		23.8%		
Education							$X_1^2 = 12.35$
• Middle school	18.6%				38.1%		$p = .002$
• High school	18.7 %		14.3%		23.8%		
• University	62.8%		85.7%		38.1%		
Qi Gong experience							
Years	8.54	5.97	5.64	4.38	11.43	6.02	$t_{36.53} = 3.56$ $p = .001$
∅ days p. week	3.34	1.62	3.81	1.4	2.88	1.72	$t_{40} = 1.92$ $p = .002$q
∅ minutes p. practice	53.74	50.48	77.24	58.25	30.24	25.91	$t_{27.61} = 3.38$ $p = .002$
Duration of Qi Gong exercise in the experiment							
Qi Gong 1	10:38	02:37	12:18	01:45	08:58	02:21	$t_{40} = 5.18$ $p = < .001$
Qi Gong 2	10:47	02:22	12:19	01:20	09:16	02:15	$t_{40} = 5.34$ $p < .001$

Note. Average days of Qi Gong practice per week (∅ days p. week); Average duration in minutes per practice (∅ minutes p. practice).

Measures

Subjective state

To monitor Subjective Vitality prior to, during and after the measurement, two items from the Subjective Vitality scale (Ryan & Frederick, 1997) were used as indicator items (“I feel vital and alive”; “I have energy and spirit”). The items were framed as ”At the moment…”. The average inter-item correlation in this study was $r_M = .87$.

To characterize the state induced by the practice of Qi Gong in more detail, we included two items to mirror Thayer’s (2001) theory of calm energy (”I feel calm”, ”My body feels activated”) and three items expected to capture Qi Gong’s impact as a form of meditative movement (Larkey et al., 2009, ”I feel pleasure in my body”, ”My attention is focused”, ”I can sense my own body”). To validate the effect of Qi Gong from a complementary theoretical perspective, we included one item in a Qi Gong specific wording (Chow et al., 2012, ”I can feel my Qi”).

Heart rate variability

The root mean square of successive beat-to-beat (RR) differences (RMSSD) and power of the high-frequency band (HF; 0.15–0.4 Hz) were taken as indicators of vagal tone (Shaffer et al., 2014). Very-low frequency power (VLF; 0.0033–0.04 Hz) was tracked due to its known increase under physical activity and link to overall health (Bernardi et al., 1996; Shaffer et al., 2014). VLF and HF values were expected to significantly deviate from a normal distribution (Shaffer & Ginsberg, 2017), hence the natural logarithm of the respective values was used (lnHF, lnVLF). Changes of RR-interval length over time were visually examined for rhythmic patterns of change in modulation. The standard deviation of the IBI normal-normal sinus beats (SDNN) was taken as measure of overall modulation from both the sympathetic and the parasympathetic nervous system. Cardiac coherence (coherence) was calculated using the approach of McCraty and Childre (2010): 1) Identification of the maximum peak in the 0.04–0.26 Hz range of the power spectrum; 2) calculating the integral of a window of 0.030 Hz centered on that peak; 3) calculating the coherence ratio as: Peak Power / (Total Power – Peak Power).

Covariates

Qi Gong specific beliefs, years of Qi Gong experience and age were examined as potential covariates in this study. Due to a significant age difference between the two national groups, the influence of cultural background was assessed via the reexamination of the global effects in the two national subsamples. Qi Gong specific beliefs regarding the effect of Qi Gong, its relation to science and the nature of Qi were assessed on two scales (”Belief in Qi” and ”Belief in the scientific investigatablity of Qi") using seven questions in a 7-point Likert-scale format (*Don't agree at all – totally agree*). The derivation of the scales and the respective items are contained in Appendix B.

Design and Procedure

Study protocol

The study protocol consisted of four stages: an initial resting period in lying supine position (7 min), two subsequent performances of a standardized Qi Gong exercise (10 min) with a short rest in-between and a post-exercise resting period in lying supine position (7min). Prior to (t0, t1), in-between (t2) and after the Qi Gong exercise (t3, t4), the participants indicated their current subjective state on a self-report questionnaire (Appendix B, Figure B.1). Electrocardiogram (ECG) was recorded throughout the experiment using two non-reusable electrodes and a portable recording sensor (EcGMove 3, movisens GmbH) at a sampling rate of 1024 Hz. The measurement was conducted indoors and individually for each participant. Participants were given the choice to either come to a measurement room at the respective university or to perform the procedure at their usual training location (indoors). The standard moving Qi Gong exercise Baduanjin ("Eight sections of brocade") consists of eight segments, which are repeated two to six times each; five of them bilaterally. The movements are performed in a slowly flowing manner and consist of twisting, stretching and bending movements including the whole body.

Data preprocessing

ECG data export from the sensor was done using Movisens SensorManager 1.8.130. The data was imported as ecg-file, visually checked for artifacts and analyzed using Kubios HRV Premium 3.0.2. For the two resting periods, the middle 5-min segments of the 7-min resting period were used. Due to technical issues and the Qi Gong typical stretching and twisting movements of the upper body, artefacts in at least one of the four segments were present in 17 participants. If possible, artefact-free segments $\geq$ 3 minutes were used as reliably representative of the respective segment (Munoz et al., 2015). Overall, data from 10 participants (7 German, 3 Chinese) had to be excluded for the HRV analysis due to insufficient data quality. Further details are contained in Appendix B. The dataset is available under https://doi.org/10.17026/dans-x5h-ym26

Data analysis

Repeated measures ANOVA were used to assess changes in subjective state and HRV indicators over the course of the measurement. Individual contrasts were examined using post-hoc tests. In order to examine the subjective state configuration induced by Qi Gong, we compared changes in all self-report items over the resting periods (t0-t1, t3-t4) with changes over the Qi Gong period (t0-t3, t1-t3). Correlational analysis was used to explore the relation between significant changes in subjective state variables (t0-t1, t1-t2, t1-t3, t3-t4) and HRV indicators (RS0, Qi1, Qi2, RS1, RS0-Qi1, RS0-Qi2).

To examine the influence of Qi Gong belief, Qi Gong experience in years and age, we examined the correlation between these variables and significant changes in subjective state and HRV parameters of the preceding analysis. Due to a significant difference in age between the two national subgroups, the influence of cultural background was examined via repetition of the main analysis in the two national subsamples.

3.3 Results

Subjective State Following Qi Gong

All subjective state variables displayed a significant change over the course of the experiment ($p < .001$). The detailed patterns of change are contained in Table 3.2. Subjective Vitality significantly increased following the Qi Gong exercise (t1-t3; $p < .001$) and returned to a level not significantly different from initial baseline during the second resting period. Calmness was the only measure that increased during the initial resting period (t0-t1; $p = .002$) and remained at this increased level (t0-t3; $p = .001$) over time. Pleasant body sensation, focused attention, body awareness, perceived body activation and sensation of Qi increased over the course of the Qi Gong exercise (t0-t3; all $p < .002$) and remained at this level (t3-t4; all $p > .05$). Only sensation of Qi significantly decreased during the second resting period (t3-t4, $p < .001$). The general patterns of change for subjective state were similar in the Chinese and the German subsample (Appendix B).

Heart Rate Variability

All HRV parameters displayed a significant change over the course of the experiment ($p > .05$). The exact values for each parameter are reported in Table 3.3. Vagal tone (lnHF, RMSSD) significantly decreased during the first (RS0-QG1; $p < .001$) and the second Qi Gong exercise (RS0-QG2; $p < .001$) compared to the initial resting period. SDNN, lnVLF and heart rate all displayed a significant increase during Qi Gong compared to rest ($p < .006$). No significant changes between the resting conditions (RS0-RS1) and between the Qi Gong conditions (Qi1-Qi2) were found.

Changes of HRV indicators followed a similar descriptive trend in the Chinese and German subsample, however in the German sample lnHF ($p = .103$), RMSSD ($p = .106$) and SDNN ($p = .156$) did not reach significance.

Table 3.2. Changes in Subjective Vitality and subjective state during rest and Qi Gong in the overall sample

Overall sample $N = 39$	Rest 0 t0-t1	Qi Gong t0-t3	Qi Gong t1-t3	Rest 1 t3-t4	Overall F
Subjective Vitality	◯ .223	↗ <.001	↗ <.001	↘ .018	19.79 <.001
Calmness	↗ .002	↗ .001	◯ >.99	◯ >.99	11.58 <.001
Pleasant body sensation	◯ .163	↗ .002	◯ .052	◯ >.99	11.66 <.001
Focused attention	◯ .864	↗ <.001	↗ .004	◯ >.99	14.38 <.001
Body awareness	◯ >.99	↗ <.001	↗ <.001	◯ >.99	12.66 <.001
Perceived body activation	◯ >.99	↗ <.001	↗ <.001	◯ .051	24.58 <.001
Sensation of Qi	◯ .118	↗ <.001	↗ <.001	↘ .003	36.4 <.001

Note. Results for post-hoc comparisons are reported for the change over the first resting period (Rest 0, t0-t1), the difference between initial baseline and following 2^{nd} Qi Gong (Qi Gong, t0-t3), the difference after first rest and after 2^{nd} Qi Gong (Qi Gong, t1-t3) and the difference before and after the 2^{nd} resting period (Rest 1, t3-t4). ↗ significant increase, ↘ significant decrease; ◯ no significant change at $\alpha = .05$, p -values of post-hoc test reported underneath.

Table 3.3. Estimated means, standard errors, 95% confidence intervals and overall F-test for all HRV parameters in the overall sample

Overall sample ($N = 32$)	RS_0	SE CI	Qi_1	SE CI	Qi_2	SE CI	RS_1	SE CI	F	p
lnHF	6.04	0.29 [5.45; 6.62]	4.84	0.22 [4.39; 5.29]	4.78	0.2 [4.37; 5.2]	5.78	0.28 [5.21; 6.36]	20.01	<.001*
lnVLF	6.17	0.17 [5.83; 6.51]	7.37	0.18 [7.0; 7.74]	7.45	0.18 [7.1; 7.81]	6.3	0.19 [5.93; 6.7]	31.71	<.001*
Coherence	0.43	0.06 [0.3; 0.56]	0.49	0.06 [0.36; 0.61]	0.49	0.07 [0.36; 0.63]	0.34	0.05 [0.24; 0.43]	1.97	= .14
SPCoherence	0.79	0.12 [0.55; 1.04]	1.38	0.33 [0.71; 2.05]	1.35	0.13 [1.08; 1.63]	0.64	0.09 [0.46; 0.82]	4.35	= .025*
RMSSD	49.43	6.71 [35.74; 63.12]	22.96	1.81 [19.26; 26.66]	23.69	1.18 [19.91; 27.48]	47.77	7.67 [32.12; 63.42]	14.93	<.001*
SDNN	52.74	5.09 [42.36; 63.11]	65.26	4.53 [56.01; 74.51]	65.81	4.27 [57.11; 74.51]	53.04	5.61 [41.6; 64.48]	6.86	= .006*
HR	66.46	1.67 [63; 69.93]	89.85	1.49 [86.81; 92.9]	91.78	1.63 [88.45;95.1]	65.95	1.6 [62.69; 69.22]	267.41	<.001*

Note. lnHF - natural logarithm of the high frequency band; lnVLF - natural logarithm of the very low frequency band; coherence - cardiac coherence; SPcoherence - spline-interpolated coherence (all frequencies < .004Hz excluded): RMSSD - root mean square of successive R-R differences; SDNN - standard deviation of the normal (NN) inter-beat intervals; HR - heart rate.

Coherence

No significant overall change in coherence was found (p = .14). Visual inspection of the power distribution graphs showed a peak around the frequency of 0.6 Hz in the LF band and a peak in the VLF band of multiple participants (Figure 3.1). Using a spline interpolation (SP) filter for all frequencies < .04Hz (VLF), a significant overall difference in spline interpolated cardiac coherence (SPcoherence) resulted (p = .025). Post-hoc contrasts revealed SPcoherence to be significantly higher during the second Qi Gong exercise compared to the resting baseline (RS0-Qi2; p = .011). SPcoherence during the second rest did not deviate significantly from SPcoherence during initial rest (RS0-RS1; p = .131).

The effect for SPcoherence was only found in the Chinese sample F (1.3, 22.3) = 6.37, p = .013, partial η^2 = 0.27, whereas the German sample did not display an overall difference between conditions (p = .57).

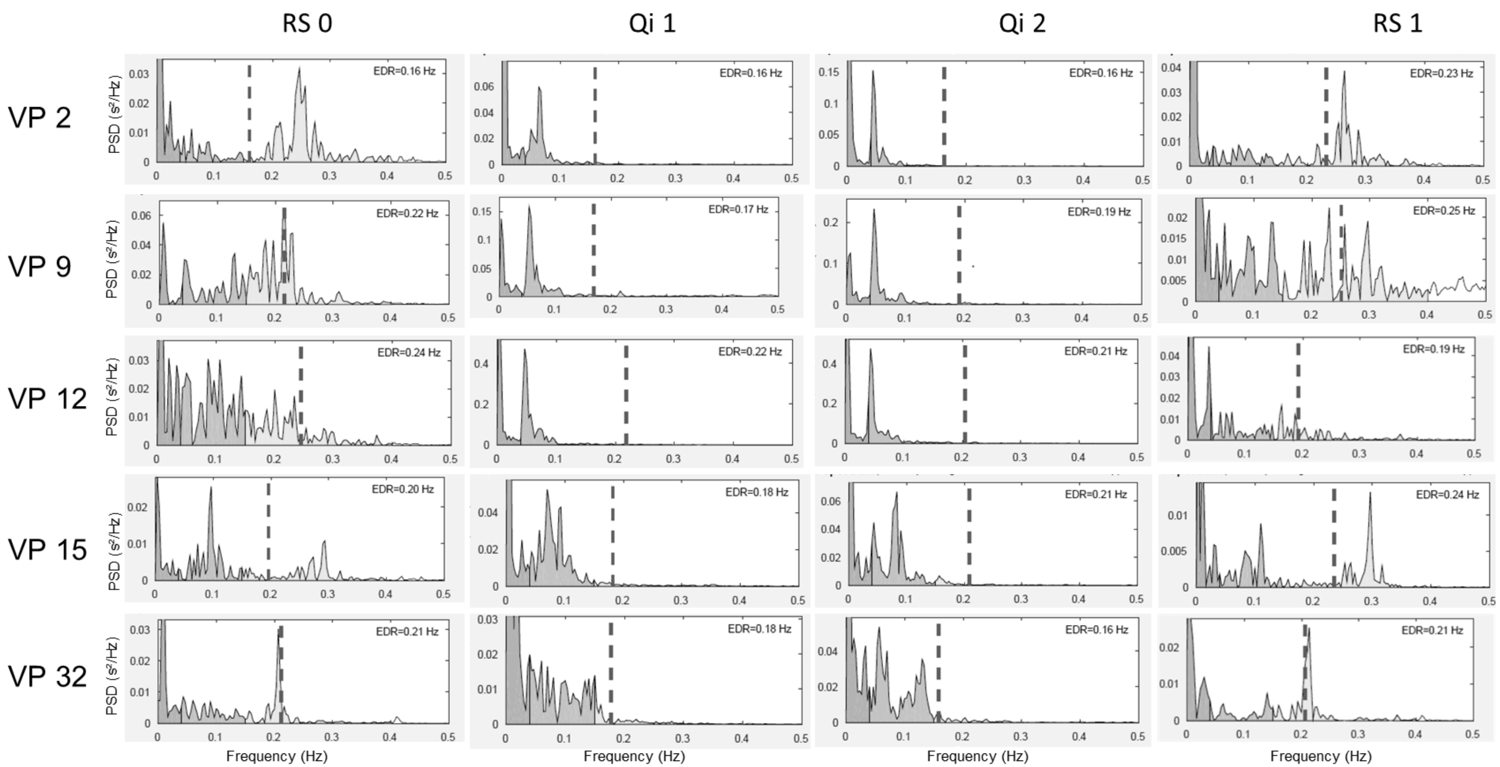

Figure 3.1. Frequency power distribution in five sample participants. Power spectra of five different participants during initial rest (RS 0), first Qi Gong (Qi 1), second Qi Gong (Qi 2) and second rest (RS 1). VP 2, VP 5, VP 9 and VP 12 from the Chinese sample are examples who display a high degree of VLF-band corrected (< .004Hz) coherence (SPcoherence) at a peak around 0.05Hz. VP 15, also from the Chinese sample is an example for medium SPcoherence and VP 32 from the German sample displays no SPcoherence.

Subjective State and HRV – Explorative Correlation

Overall sample

No significant correlations were found between changes in subjective state variables (t1-t2, t1-t3) and changes in HRV parameters (RS0-Qi1, RS0-Qi2) or HRV parameters (Qi1, Qi2) in the overall sample. Decreases in perceived body activation (t3-t4) during second rest (RS1) were stronger in participants with higher RMSSD, r = .33, p =.046, higher lnHF, r = .33, p = .048 and lower heart rate, r = -.43, p =.003.

National subsamples

In the German sample a stronger increase in heart rate during the first Qi Gong (RS-Qi1) was associated with a stronger increase (t1-t2) in Subjective Vitality, r = .52, p = .045, perceived body activation, r = .67, p = .006 and perception of Qi, r = .82, $p < .001$. A stronger increase in heart rate during the second Qi Gong (RS0-Qi2) correlated with a stronger increase in body awareness (t1-t3), r = .57, p = .02 (RS0-Qi2). Decreases in perceived body activation (t3-t4) during second rest were stronger in participants with higher RMSSD, r = .65, p = .006, higher lnHF, r = .52, p = .04 and lower HR, r = -.67, p = .004. Furthermore, decreases in Subjective Vitality over the second rest (t3-t4) were stronger in participants with higher RMSSD, r = .59, p = .015.

In the Chinese subsample participants who showed a higher increase in Subjective Vitality (t1-t2) after the first Qi Gong exercise also showed a marginally significant stronger decrease in RMSSD, r =-.42, p = .064. A stronger increase in body awareness (t1-t3) was correlated with decrease of lnHF, r = -.51, p = .03 (RS0-Qi2). High SPcoherence during the second Qi Gong exercise (Qi2) correlated marginally significant with increases (t1-t3) in Subjective Vitality, r = -.46, p = .056 and significantly with perception of Qi, r = -.51, p = .03.

Covariates - beliefs, experience, age

Participants who believed more in Qi showed a higher increase in attentional focus, r = -.33, p = .037 (t1-t2), r = -.37, p = .014 (t1-t3) and a stronger decrease in body activation during second rest, r = -.32, p = .038 (t3-t4). Belief in the accessibility of Qi to scientific investigation correlated with less perception of Qi, r = .34, p =.028 (t1-t3) following Qi Gong. Years of Qi Gong experience did not correlate significantly with any changes in subjective state in the overall sample. Older participants showed a significantly higher increase in SV following Qi Gong (t1-t3), r = -.44, p = .003.

Participants with a stronger belief in Qi showed a significantly higher increase in SDNN, r = -.33, p = .047 (RS0-Qi1). Subjects with a stronger belief in the accessibility of Qi to scientific investigation showed less increase in lnVLF, r = .36,

p = .037 (RS0-Qi1) during the first Qi Gong exercise. Older participants showed significantly less decrease in measures of vagal modulation (RMSSD, lnHF): RMSSD, r = -.51, p = .001 (RS0-Qi1), r = -.59, p < .001 (RS0-Qi2); lnHF, r = -42, p = .011 (RS0-Qi1), r = -.54, p < .001 (RS0-Qi2) and less increase in HR, r = .68, p < .001 (RS0-Qi1), r = .70, p = < .001 (RS0-Qi2). Qi Gong experience in years showed weaker correlations for the same variables as age; however, when controlled for age, none of the correlations remained significant (all p > .10).

3.4 Discussion

The overall goal of this study was to explore the psychophysiological mechanism underlying mind-body exercise using the example of a standard moving Qi Gong exercise (Baduanjin). Two bouts of Baduanjin effectively induced a state of Subjective Vitality, characterized by high calmness and perceived body activation, increased attention and body awareness, accompanied by pleasurable body feelings. On a physiological level, vagal tone (lnHF, RMSSD) significantly decreased whereas overall modulation (SDNN), physiological activation (lnVLF and heart rate) and SPcoherence significantly increased during Qi Gong.

A Mechanism of General Activation

Our findings of a decrease in vagal tone during the exercise are in line with views of Qi Gong as moderate aerobic exercise (Hartley et al., 2015; Meng et al., 2018) and its acute effects (Leicht et al., 2008; Michael et al., 2017; Tulppo et al., 1998) potentially needed for long-term health adaption processes (Besnier et al., 2017; Routledge et al., 2010). The findings support Qi Gong's assumed capacity for moderate up-regulation as one component to reach a state of eutonic calmness (Payne & Crane-Godreau, 2013). From a general health perspective, the mechanism of moderate activation highlights a route to explain long-term beneficial effects of mind-body exercise on hypo-aroused conditions such as fatigue (Wayne et al., 2018) and depression (Zou et al., 2018). One interesting point is that the average HR in this study did not raise above levels of moderate activation (> 100BPM) which can be achieved solely by parasympathetic withdrawal (Robinson et al., 1966; White & Raven, 2014). Hence, this form of activation may comprise benefits of moderate activation without potential draining effects of top-down modulated sympathetic activation (Kemp et al., 2017; Taylor et al., 2010; J. Thayer et al., 2012).

On the experiential level, changes in vagal tone (RMSSD, lnHF) displayed negative, indicators of activation (HR, lnVLF) positive correlations with perceived body activation and Subjective Vitality. These findings underline the general activating aspect of body-mind exercise via its influence on energy (R. Thayer, 2012) and Subjective Vitality as activated positive emotion (Henz & Schöllhorn, 2018; Johansson

& Hassmén, 2013; Ryan & Bernstein, 2004).

A Mechanism of Micro-activation

Regulation, as in the context of this study, emphasizes the conjunct presence of activation (up-regulation) and relaxation (down-regulation). The rhythmic rise and decline in RR-interval length, displayed for an exemplary subject in Figure 3.2, indicates such a pattern of micro-regulation. The pattern drives the significant increase in the overall standard deviation of RR-intervals (SDNN) and its regularity displays in the significant increase of SPcoherence at a peak frequency between 0.05 and 0.07Hz. This frequency aligns with rhythmic changes in movement and potentially breath and inner imagery (Chen & Liu, 2010) during Qi Gong in this study: The eight segments of Baduanjin Qi Gong each consist of an "up-regulation" (e.g., lifting arms palms facing the sky, breathing in) and a "down-regulation" (e.g., falling arms at the side of the body, breathing out) part, repeated six times per segment. In the example of the Chinese subgroup this leads to a calculated frequency of 0.64Hz (12:19min /48 movements) for the second Qi Gong exercise that matches the SPcoherence peak between 0.05 and 0.07 Hz. Increases in VLF band activity initially covered a significant increase in coherence, however they are in line with effects of exercise on the power spectrum (Bernardi et al., 1996).

Based on the preceding analysis, in this study the increase in SDNN can be interpreted as a marker of overall increase in regulation. As other forms of exercise tend to show a decrease in SDNN (Leicht et al., 2008) the increase in SDNN displays a potential characteristic of body-mind exercise. Studies that find stable increases in SDNN following long-term Qi Gong interventions provide first evidence for the transference and stability of this increased regulative capacity (M.-Y. Chang, 2015; Lee et al., 2018). Overall, we suggest that regulation via bottom-up ANS pacemaking in Qi Gong invites healthy oscillating capacity in the organism (Mather & Thayer, 2018; J. Thayer et al., 2012) and comprises the second and characteristic health mechanism of body-mind exercise.

On a subjective level, this second physiological mechanism links to the dimension of calmness (R. Thayer, 2012) and Subjective Vitality as a marker of regulative capacity (Muraven et al., 2008). Changes in these variables, as well as the increase in attentional focus, the awareness of one's own body and pleasurable body feelings (Larkey et al., 2009) confirm mind-body exercise's capacity to reach a state of eutonic calmness or relaxed attentiveness with a focus on the body (Henz & Schöllhorn, 2018; Payne & Crane-Godreau, 2013).

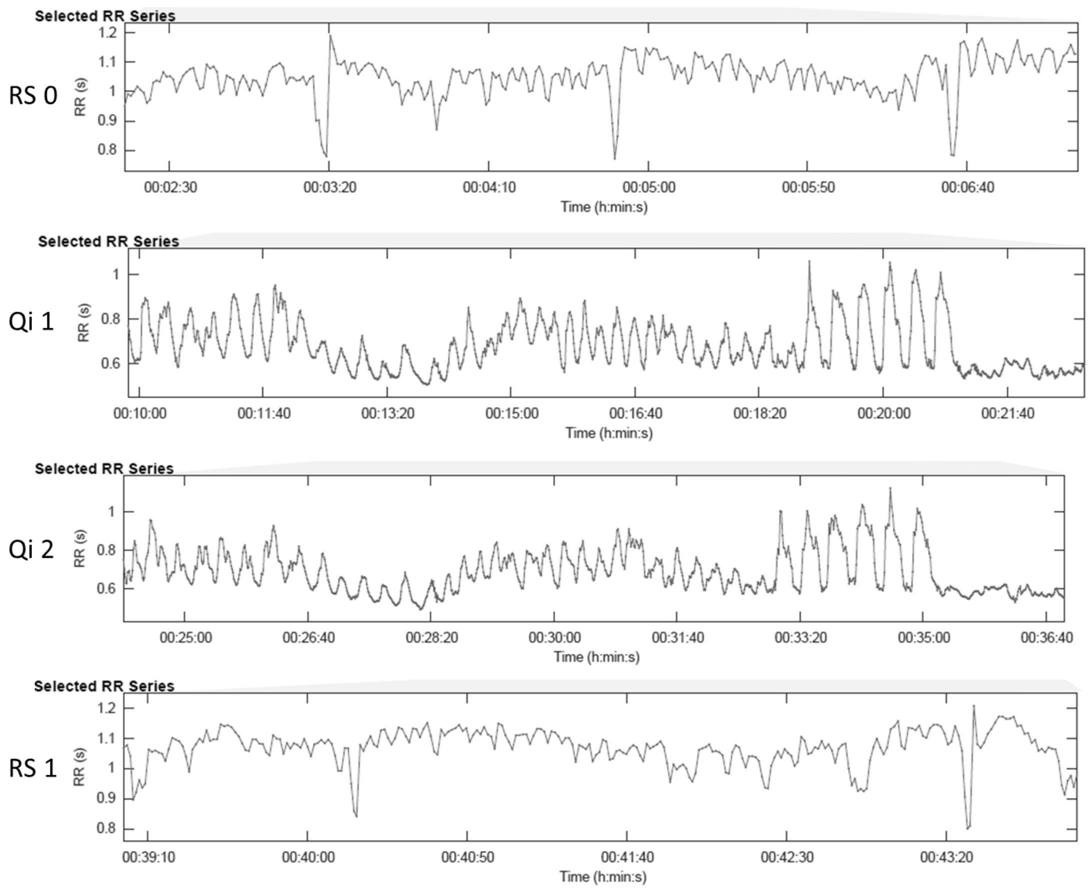

Figure 3.2. Sample RR-interval trajectory during rest and Qi Gong. RR interval series of VP12 for initial rest (RS 0), the first Qi Gong exercise (Qi 1), the second Qi Gong exercise (Qi 2) and the resting period following Qi Gong (RS 1). VP12 displayed a high degree of SPcoherence (3.1). This figure shows the rhythmic changes (around 0.05Hz) in RR intervals associated with activation and relaxation during Qi Gong

Multicomponent Intervention – Covariates and National Subsamples

Overall, the decrease of vagal tone (lnHF, RMSSD) and increase of lnVLF band power was less pronounced in older participants. This is in line with age-related changes of HRV during rest and exercise in general (Shaffer & Ginsberg, 2017; Tulppo et al., 1998). Furthermore, the finding offers an explanation for inconclusive results regarding resting state HRV changes following long-term Baduajin training protocols in different age groups (M. Li et al., 2015; R. Li et al., 2014; Ying et al., 2019). Regarding the difference between the two samples, the significant higher age in the German subsample in this study (56.3 vs 28.8 years) may have been a reason for the finding of less pronounced changes in HRV parameters and differences in subjective state - physiology correlations. Furthermore, the majority of the German participants (n = 17) were recreational practitioners compared to the Chinese sample with a professional Qi Gong training background (University degree). The difference in SPcoherence increase could have resulted from differing amounts of deliberate practice (Ericsson & Lehmann, 1996). In line with this argument is that in the Chinese subsample years of Qi Gong experience correlated significantly with an increase in body awareness (t1-t3: r = -.70, p < .001), perception of Qi (t1-t2: r = -.47, p = .031) and Subjective Vitality (t1-t3: r = -.44, p = .045) beyond the explanatory power of age which matches findings of body awareness as a marker of expertise in body-mind exercise (Sze et al., 2010).

The significant influence of Qi Gong specific beliefs found in this study confirmed Qi Gong's nature as a multicomponent intervention (Wayne & Kaptchuk, 2008a, 2008b).

Limitations

This study several limitations: The use of a quasi-experimental design in this study limits the possibilities for causal conclusions. Due to the significant difference in age no direct comparison between the two subsamples was possible. Furthermore, participants were allowed to take the measurements in their usual training location or at the respective university. In this way, potential effects of environmental factors could not be ruled out. A further limitation was the limited recording time following the completion of the second resting period. We found that most subjective and all HRV parameters returned to baseline during the second resting period; a following change in one of the parameters could not have been detected in this design. Furthermore, to specifically measure the regulative effect of Qi Gong, future studies should use passive (e.g., standing,) and active (e.g., walking) as well as hypo-aroused (e.g, autogenic training) and hyper-aroused (e.g., stress task) control conditions.

3.5 Conclusion

Overall, we found that the Qi Gong form of Baduanjin reliably induced a state of Subjective Vitality associated with moderate vegetative activation and rhythmic micro-regulation within the ANS. The subjective state following Qi Gong entails a specific profile of calm activation linked to activated positive affect, body awareness and regulative capacity. Linking back to the initial question, the findings suggest a mechanism of moderate general activation in combination with a pattern of micro regulation via movement, breath and imaginary to be the health beneficial characteristic of body-mind exercise.

Chapter 4

Daily Subjective Vitality and Vagal Tone

Abstract

Subjective Vitality holds great promise as a salient indicator of health, linking the complex bio-psycho-behavioral dynamics of human well-being. Daily interactions of SV, vagal tone, physical activity and psychological need satisfaction were therefore explored in an intense longitudinal design in eight depressed inpatients over the course of a residential psychotherapy (13-26 days). Higher SV was associated with higher levels of physical activity, vagal tone as well as feelings of competence, relatedness and autonomy on the same day. A similar correlational structure with negative associations was attained when using daily ratings of symptom intensity instead of SV. All individuals displayed a significant improvement in trait SV. Examination of the SV trajectories revealed that daily SV tended to change in non-incremental ways. Overall, this study highlights the potential of SV as an integrative marker of health and the strengths of a multi-layered dynamic network approach in the study of well-being.[4]

[4]Goldbeck, F., Aas, B., Sudeck, G., Hautzinger, M., Fallgatter, A.J., and Ehlis A.-C. (submitted). How is your energy today? A dynamic network perspective on daily changes in Subjective Vitality, need satisfaction, physical activity and vagal tone in depressive inpatients.

4.1 Introduction

Feeling vital and alive is one key indicator of health and the good life (Ryan & Bernstein, 2004) – reduced drive and energy a prominent sign of mental and physical illness (Watanabe et al., 2008). As a main criterion of disorders in the depressive spectrum, loss of drive is a major cause for the diseases' constraining impact on people's lives and its economic burden to society (Evans-Lacko & Knapp, 2016). In contrast, Subjective Vitality, "the feeling of aliveness and possessing personal energy", is described as a dynamic indicator of organismic well-being (Ryan & Deci, 2008; Ryan & Frederick, 1997). Despite the central role of "lack in experienced energy" in depressive symptomatology (Fried et al., 2016), not much is known about its day-to-day changes over the course of a depression treatment. Furthermore, factors associated with health improvement and the increase of Subjective Vitality, such as basic psychological need fulfillment (Ryan, Bernstein, et al., 2010; Ryan & Deci, 2008), physical activity (Duda et al., 2014; Solberg et al., 2012) and changes in heart rate variability (Kemp & Quintana, 2013) have rarely been examined in their mutual and potentially beneficial interactions over the time of a treatment. The present study therefore applied a multi-layer dynamic network approach (Borsboom & Cramer, 2013; Epskamp et al., 2016) using simultaneous, high-resolution time series of variables from distinct layers in the human organism (physiology, subjective experience, needs, behavior) to explore the dynamics underlying interventions and changes of human well-being.

Dynamic Networks

Psychotherapy has been proven effective for the alleviation of depressive symptoms (Munder et al., 2019). However, how this process enfolds with regard to changes in Subjective Vitality is not well known. Two approaches to explore these questions have recently gained new momentum in psychotherapy research: The organization of psychological phenomena in networks (Borsboom & Cramer, 2013; Schiepek, 2003) and their dynamic development over time (Hamaker & Wichers, 2017; Schiepek & Strunk, 2010). In its recent form, the network approach has been introduced in personality research and psychopathology (Borsboom & Cramer, 2013), emphasizing interactive patterns between observable variables instead of a latent disease mechanism. The second development has been the application of uni- and multivariate intensive time series analysis to study changes of psychological phenomena over time (Epskamp et al., 2016; Hamaker & Wichers, 2017). The goal of this study was to combine these two approaches in an exploratory design to study the multi-layer dynamics of health on the example of Subjective Vitality in patients with depression.

Vitality as a Network – Needs, Physical Activity and Vagal Tone

Subjective Vitality has been described as a marker of organismic well-being (Ryan & Frederick, 1997). To explore "organismic" interactions linked to changes in Subjective Vitality, we included variables from the psychological (basic psychological needs), the behavioral (physical activity) and the biological/physiological (vagal tone) perspective on the organism.

Only few studies thus far, have examined Subjective Vitality over time. One unambiguous finding for healthy population samples is that the satisfaction of basic psychological needs for autonomy, relatedness and competence increases Subjective Vitality in people on a day-to-day basis (Reis et al., 2000; Ryan, Bernstein, et al., 2010). No prior evidence exists for clinical samples.

One behavioral indicator abnormal in depression and associated with Subjective Vitality is physical activity. Physical activity has proven to be reduced in depression (Schuch et al., 2017) and accumulating evidence indicates that physical activity is also effective in elevating states of depression (Schuch, Vancampfort, Richards, et al., 2016). Different types of exercise have displayed the capacity to increase state and trait levels of Subjective Vitality (Duda et al., 2014; Solberg et al., 2012), however, so far only studies using positive affect as a variable have investigated the association with physical activity in a time-series design (Curtiss et al., 2019; Stavrakakis et al., 2015). Stavrakakis et al. (2015) used a within-subject time-series approach to investigate the dynamic relationship between physical activity and affective state in depressed and non-depressed individuals. The authors found high variability in the relationship between affect and physical activity – the only relatively stable direct relationship being the one between physical activity and positive affect. In healthy population samples, physical activity has been associated with increased positive affect and energetic arousal (Liao et al., 2015; Sudeck et al., 2016).

To complement the multi-layer dynamic network perspective, vagal tone was included as a physiological marker relevant to outcomes of well-being and depression (Kemp & Quintana, 2013; Kemp et al., 2010). High-frequency power (HF), calculated from the variation of inter-beat intervals in a given time window of the human heart, has been associated with vagal tone (Shaffer et al., 2014) and found significantly decreased in depressed individuals (Kemp et al., 2010). No studies have assessed the explicit relationship between vagal tone and Subjective Vitality; however, the association between positive affect and vagal tone has been researched (Duarte & Pinto-Gouveia, 2017; Kemp & Quintana, 2013; Kok et al., 2013; Schwerdtfeger et al., 2015; Schwerdtfeger & Gerteis, 2014; Sloan et al., 2016). Findings are equivocal with regard to activated positive emotions (Duarte & Pinto-Gouveia, 2017; Schwerdtfeger et al., 2015; Schwerdtfeger & Gerteis, 2014) but also correlation in general (Sloan et al., 2016). Regarding associations over time, Kok et al. (2013) reported evidence for a reciprocal positive relationship between social connectedness, positive emotion and vagal tone. Aggregated deactivated positive affect seems to correlate with higher vagal tone during nighttime (Schwerdtfeger et al., 2015), whereas aggregated activated positive affect positively correlates with momentary vagal tone (Schwerdtfeger & Gerteis, 2014).

Trajectories and Critical Instabilities

Intensive time-series modeling allows to capture the process of change in a variable as it unfolds over time (Hamaker & Wichers, 2017). A rising number of studies in the field of psychotherapy indicate that change trajectories are characterized by features of complex system dynamics (Schiepek et al., 2014; van de Leemput et al., 2014; Wichers et al., 2016). A perspective, well-established for other phenomena like financial markets or ecosystems (Scheffer et al., 2012). As a result, a patient's process of change over time (e.g., daily ratings of affect) may better be described by tipping points (van de Leemput et al., 2014; Wichers et al., 2016), phase transitions and critical fluctuations of a dynamic system than by incremental linear gains (Heinzel et al., 2014; Schiepek et al., 2014). Some first evidence has shown that on- and offset of depression shows a significant association with *critical slowing down*, i.e. an increase in auto-correlation in the time series of patients (Curtiss et al., 2019; Olthof et al., 2019; van de Leemput et al., 2014; Wichers et al., 2016). Other research found that a local increase in the complexity of a time-series, i.e. an increase in fluctuation and distribution of ratings in a given time-window, predicts symptom improvement of patients with obsessive-compulsive disorder (Heinzel et al., 2014; Schiepek et al., 2014).

The Present Study

The present study tracked daily feelings of Subjective Vitality, symptom severity and basic psychological need satisfaction over the course of a residential treatment in depressive inpatients. Furthermore, physical activity and vagal tone from daily resting state measurements were recorded to assess the interrelations of subjective and objective vitality markers over time. The resulting trajectories of daily levels of Subjective Vitality were explored for trends of non-incremental development and properties of complex dynamic systems (critical slowing down, increased complexity), predictive of change in treatment outcomes.

We assumed that trait Subjective Vitality, physical activity and vagal tone would significantly increase and depressive symptomatology decrease, following residential psychotherapy to a level not significantly different from healthy controls. Daily changes in Subjective Vitality were expected to be positively correlated with basic psychological need satisfaction and the daily amount of habitual physical activity. The relationship between daily Subjective Vitality and vagal tone was also expected to be positive. The resulting time-series for state Subjective Vitality were expected to be non-linear and to display patterns of critical slowing down and local increase of complexity associated with higher rates of change in pre-post outcome measures of trait Subjective Vitality and depressive symptomatology.

4.2 Material and Methods

Sample

Eight participants and an age-matched control sample were recruited at the Systelios Clinic, Siedelsbrunn in cooperation with the University Hospital Tübingen. The clinic is a psychosomatic acute clinic with a standard implementation of the Synergetic Navigation System (SNS; Schiepek et al., 2016) which allows for daily collection and monitoring of individual patient data. Over a six-month period, all incoming patients were screened and included when meeting the following inclusion criteria upon their arrival: diagnosis of a first-time or recurrent major depression (F32.1./F33.1) by a local clinician, no comorbid disorders, no acute cardiovascular disease or diabetes, no acute medication. Of 22 clients who met the inclusion criteria 16 agreed to participate in the study. Three participants quit the study protocol due to early discharge. Three participants took up medication and two were excluded from the analysis due to insufficient compliance (Missing observations $> 30\%$). The data of eight participants was used in this study; descriptive statistics are displayed in Table 4.1. Age- and sex-matched healthy controls without current psychological disorders were recruited among the non-therapeutic staff of the clinic. All participants provided informed consent in accordance with the current guidelines of the World Medical Association's Declaration of Helsinki. The study was approved by the Ethics committee at the University Hospital and University of Tübingen.

Measures

Pre-post measurement

Depression Status of depression in the sample was assessed using the German adaptation of Becks Depression Inventory (BDI; Hautzinger, 1988). A higher rating indicates a stronger degree of depression (cut-off for no clinical impairment ≤ 12).

Trait Subjective Vitality The German adaption of the Subjective Vitality scale (Goldbeck et al., 2019; Ryan & Frederick, 1997) in its six-item version was used to assess trait levels of Subjective Vitality. The items covering one's feeling of energy, spirit and alertness are being answered with regard to how participants rate each statement to their life in general on a 7 point Likert-scale (Range 7 – 42).

Daily Measurements

Daily Subjective Vitality For the daily monitoring of Subjective Vitality, two items ("Today I felt vital and alive", "Today I had energy and spirit") of the Subjective Vitality scale were adapted and added into one sum score. In adjustment to the digital SNS system, the items were displayed as visual analog scales on a computer screen with two end points (*not at all – very much*) and patients had to use the mouse to place a marker on the scale. Location on the scale was transformed by the system into a scale between 0 and 100. The range for the final sum score was 0-200.

Psychological Needs To assess the daily degree of need fulfillment for autonomy and competence, participants were asked to think about the three activities they had spent most time with on this day and rate how self-determined/competent they had felt during that activity. To determine the need for relatedness, participants were asked to think about their three longest interactions with other people they had during the day and rate how close and related they had felt during that interaction. All three ratings were made on visual analog scales similar to the ones for Subjective Vitality.

Symptom severity To have a contrasting state marker of illness, patients indicated a daily response to the question "Today, my symptoms were..." (*not at all present – very strong*) on a visual analogue scale in the format above.

Vagal tone The high-frequency component (HF; 0.15–0.4 Hz) calculated from a given segment of RR inter-beat-intervals in the human heart is indicative of vagal tone (Shaffer & Ginsberg, 2017). Daily resting state short-term ECG recordings (5 min) in supine position were used as a basis for the calculation. For the recording, two non-reusable electrodes and a portable sensor (EcGMove 3, movisens GmbH) were attached according to the movisens manual below chest level of the left upper body. ECG data was recorded at a sampling rate of 1024 Hz.

Physical activity (steps) Physical activity was assessed via accelerometry using the Move 3 sensor (movisens GmbH). The sensor measures participants' acceleration on three axes with a sampling rate of 64 Hz. For means of better interpretability, acceleration (m/s^2) was converted into *steps* per day by vector summation of the three axes, low-pass filtering and high/low-point search under specific plausibility criteria implemented in the movisens Data Analyzer 1.8.13023 (Anastasopoulou et al., 2013). Participants wore the sensor attached to the right hip over the entire day and took it off when sleeping, swimming, or taking a shower.

Design and Procedure

Patient sample Upon arrival in the clinic, participants underwent a standard physical examination and a diagnostic interview with their respective therapist. If eligible for participation, the experimenter confirmed with the physician in charge and the patient received a flyer with study information. Patients interested in participation were scheduled for an initial interview within the first 10 days of their stay. The interview consisted of a section about their personal vitality factors and related questions for their daily questionnaire (not reported in this study). Further on, they received an introduction to the questionnaires, accelerometer and resting HRV measurement. Participants then filled out the pre-measures of trait Subjective Vitality and depressive symptoms.

Daily self-report measures were answered online using the SNS. Each day's questionnaire was activated at 5 pm and could be filled out during the following days in case of a miss. Daily ECG resting state measurements of 7 minutes duration in supine position were taken individually in a separate room between 6 and 8 pm. During the measurement participants were instructed to close their eyes, breathe normally and to not think of anything in particular. The experimenter remained in the room and announced the beginning and the end of the measurement. Measures were not taken in case of a weekend absence of the participant. Accelerometer data was saved every 5 days, and every two weeks the participants had the option to review their own data in an aggregated version and discuss questions with the experimenter. Participants did not differ in their received amount of therapy treatment per week (3 single sessions, 8 group sessions).

Control group Healthy control participants carried an accelerometer for three days and underwent ECG resting state measurement in the same time period under conditions similar to the patient group. Trait measures of Subjective Vitality and depressive symptoms were filled out once at the first day of measurement.

Data analysis

Data preprocessing ECG raw data was exported from the Move 3 sensor using Movisens SensorManager 1.8.130. For each observation, the middle 5-min segment from the 7-min measurement was used for analysis and inspected visually for artefacts using UnisensViewer. Artefacts were marked and excluded for the calculation of power in the HF band using the batch mode of DataAnalyzer 1.8.13023 (movisens, GmbH). For the calculation of physical activity, raw acceleration data was transferred from the sensor and calculated as the daily number of steps using movisens DataAnalyzer 1.8.13023. Daily individual self-report data was exported from the SNS in an excel file and merged with daily measures of vagal tone and number of steps in an overall file. The statistical analyses were conducted using IBM SPSS Statistics 25 and R

3.6.0. The data set is available under https://doi.org/10.17026/danszu7-rv3g

Pre-post comparison Wilcoxon Signed-Rank tests were used to examine pre-post changes in trait levels of Subjective Vitality and depression in the patient sample. Man-Whitney-U tests were used to compare post-levels of the respective variables in the patient sample with the healthy control group. To compare average levels of physical activity and vagal tone between controls and the patient sample, the data was averaged over the first three and the last three observations in the patient sample and compared to the averaged three observations of the control group using Mann-Whitney-U Tests.

Dynamic network analysis Prior to the analysis of the time series data, the structure of missing data was examined and missing data imputed via Bayesian regression using all other variables as predictors (Buuren & Groothuis-Oudshoorn, 2010). Due to the potential effect of change over the course of the treatment, every variable was examined for significant linear trends and detrended in case of a significant linear trend to meet the criteria of stationarity (Bringmann et al., 2015) for the following network analysis. In multilevel vector-auto-regressive (mlVAR) network estimation (Epskamp et al., 2016), a given variable at time t is regressed onto all other time lagged t-1 independent variables (*temporal network*). From the residuals of the temporal network a *contemporaneous network* (other variables at t) can then be estimated in a second step. In the networks every variable is considered a node. Edges between nodes reflect directed partial regression coefficients and each directed edge (in the temporal network) reflects a unique association between two nodes controlling for all other associations in the network. The models were estimated using correlated random effect estimation to allow exploration of significant edges based on individual information use in a small sample with relatively few observations (Epskamp et al., 2016). Temporal and contemporaneous networks were estimated for two variable constellations: The first included Subjective Vitality, steps, lnHF and the three basic psychological needs. In the second selection, reported symptom severity replaced Subjective Vitality as a node. Due to the exploratory nature of the study, an edge was retained if one of the two regressions on which the partial correlation is based was significant at the $\alpha = 0.05$ level (OR rule; Van Borkulo et al., 2014) and no correction for multiple testing was applied.

Change trajectories and critical instability To explore individual trajectories of change in daily Subjective Vitality for each patient, individual linear models, including higher order polynomials and autoregressive covariance structures, were fitted until saturation was reached. To test the Subjective Vitality time series characteristic as a dynamic complex system, the effect of critical slowing down was tested via multilevel modeling of temporal autocorrelation (Curtiss et al., 2019;

van de Leemput et al., 2014). Multilevel models were specified in a way that a variable at time t (e.g., Subjective Vitality at t) was regressed on the variable at time t-1 (auto-correlation: Subjective Vitality t-1) and the interaction between variable at t-1 and pre-post change in outcome (trait Subjective Vitality, depression). A significant interaction would indicate an association between critical slowing down (autocorrelation) and change in outcome.

The complexity of the Subjective Vitality time series was quantified as product of the fluctuation (F) and the distribution (D) of the variable over a moving time window of seven days (Schiepek & Strunk, 2010). The maximum – average difference of the resulting complexity time series was taken as indicator of critical fluctuations or phase transition (Schiepek et al., 2014) and tested for significant correlation with outcome changes in trait Subjective Vitality and depression. All data is available under https://doi.org/10.17026/dans-zu7-rv3g

4.3 Results

Descripte Statistics

The mean age of the patient group was 51.1 years (SD = 12.9), six out of eight patients were female. The average number of complete observations (ECG and questionnaire) was 19.12 which is an average of 80.31% of the maximum attainable measurements. The number of observations per patient as well as the individual pre- and post-scores of Subjective Vitality and depression are displayed in Table 4.1.

Pre-post Changes and Healthy Controls

Trait Subjective Vitality improved significantly from pre-levels (M = 12.1, SD = 6.0) to post-levels (M = 25.7, SD = 3.6) in all patients, Z = -2.52, p = .012. Depressive symptoms showed a significant decrease from pre-levels (M = 24.37, SD = 2.6) to post levels (M = 7.7, SD = 7.5) in the sample, Z = -2.52, p = .012. No significant changes were found for vagal tone (p = .575) and the level of physical activity (p = .889) averaged over the first and the last three days of measurement.

Post-scores of the patient sample in Subjective Vitality did not differ significantly from trait Subjective Vitality in the control group (p = .169). Depressive symptoms were significantly higher in the patient sample (M = 7.75, SD = 1.6) at the end of the stay than in the control group (M = 1.87, SD = 1.01), U = 7.5, p = .009. Vagal tone did not differ significantly between the patient and the control group (p = .916). Physical activity was significantly higher in the control group (M = 12.274 steps/day, SD = 1549) than in the patient group (M = 7.886 steps/day, SD = 937) at the end of the stay, U = 13, p = .046. Changes in trait measures and levels of the control group are displayed in Figure 4.1.

Table 4.1. Overall sample characteristics, individual Pre-Post outcomes and observation statistics

VP	Age	Sex	Pre Vit	Post Vit	Pre Dep	Post Dep	No obs. max	No obs. (ECG/Q)	No obs.%	Q (days)	Acc	ECG (days)
1	57	M	24	30	21	15	27	26	96.3	27	26	26
2	57	F	16	29	21	5	17	14	82.4	17	15	14
3	70	F	10	28	29	8	14	13	92.9	13	14	13
4	55	F	7	26	25	12	26	21	80.8	25	26	21
7	53	F	14	26	37	4	21	15	71.8	16	16	16
8	26	F	5	26	27	10	28	22	78.6	25	23	23
14	49	F	12	22	12	1	31	21	67.7	22	27	23
16	42	M	9	19	23	7	29	21	72.4	27	27	22
M	51.1		12.12	25.75	24.37	7.75	24.12	19.12	80.31	21.5	21.75	19.75
SD	12.9		5.89	3.65	7.23	4.5	5.71	4.28	9.5	5.1	5.75	4.46

Note. Pre Vit - pre score trait SV; Post Vit - post score trait SV; Pre Dep - pre score Becks Depression Inventory; Post Dep - post score Becks Depression Inventory; No obs. max - maximum number of measurement points (duration of stay); No obs. (ECG/Q) - number of observations with concurrent ECG and questionnaire measurement; No obs % - number of observation of maximum number of observations possible in percent; Q (days) - number of days with questionnaire measurement; Akz - number of days with accelerometric data of habitual physical activity over the day; ECG (days) - number of ECG measurements for resting state vagal tone.

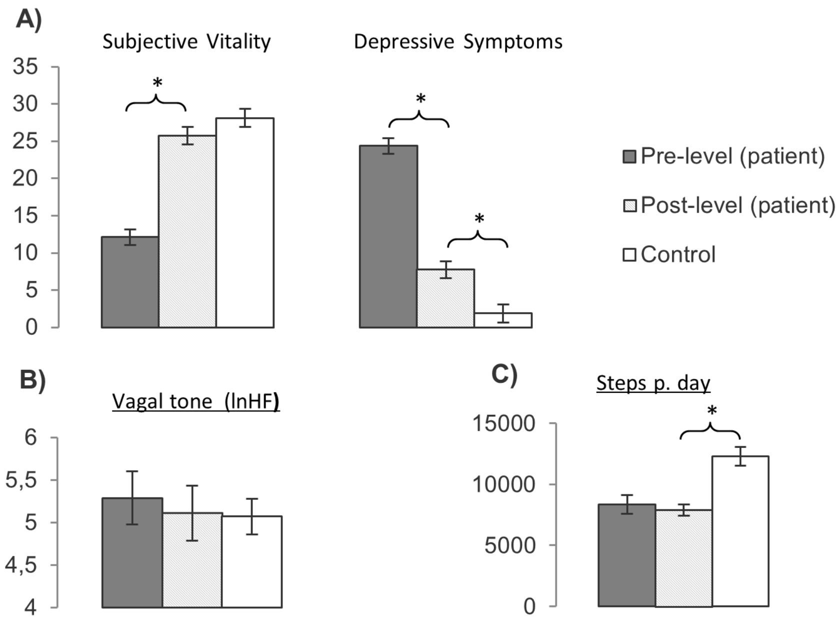

Figure 4.1. Pre-post changes and group comparisons in trait Subjective Vitality (A), depressive symptoms (A), vagal tone (B) and steps per day (C).

Network Analysis

Vitality network

The estimated contemporaneous network for Subjective Vitality revealed positive partial associations on the same day between Subjective Vitality, physical activity, r_p = .19, $p_{PA \to SV}$ = .039, $p_{SV \to PA}$ = .037 and vagal tone, r_p = .13, $p_{SV \to lnHF}$ = .045. Furthermore, significant positive estimates resulted for associations between Subjective Vitality and the feeling of competence, r_p = .25, $p_{C \to SV} < .011$, $p_{SV \to C}$ =.045, the feeling of autonomy r_p = .26, $p_{A \to SV}$ =.031, $p_{SV \to A}$ = .006, and the feeling of relatedness r_p = .28, $p_{R \to SV}$ =.025, $p_{SV \to R}$ =.009. Feelings for competence were also associated with feelings of autonomy, r_p = .31, $p_{C \to A} < .001$, $p_{A \to C}$ = .002 and feelings of relatedness, r_p =.28, $p_{R \to C}$ = .006, $p_{C \to R}$ = .007.

In the temporal network, vagal tone (lag 1) predicted vagal tone on the following day, β = -0.21, p = .001. Feelings of competence predicted physical activity, β = 0.38, p = .031 on the following day. The contemporaneous and the temporal network for Subjective Vitality are displayed in Figure 4.2.

Symptom network

In the contemporaneous symptom network, daily ratings of symptom severity showed significantly negative partial associations on the same day with vagal tone, r_p = -.16, $p_{lnHF \to Sym}$ = .049, $p_{Sym \to lnHF}$ = .026, physical activity, r_p= -.15, $p_{Sym \to PA}$ = .046, feelings of relatedness, r_p = -.26, $p_{Sym \to R} < .014$ and feelings of autonomy, r_p = -.27, $p_{A \to Sym}$ = .007, $p_{Sym \to A}$ = .002. Feelings of competence showed significantly positive partial associations with feelings of autonomy, r_p = .40, $p_{C \to A} < .001$, $p_{A \to C}$ = .001 and feelings of relatedness, r_p = .40, both $p < .001$.

In the temporal network, vagal tone was negatively associated with vagal tone on the following day, β = -0.19, p = .005. The symptom networks are displayed in Figure 4.3.

Individual change trajectories

Figure 4.4 displays the individual trajectories in daily Subjective Vitality over the course of the stay in each participant. Individual multilevel analysis revealed that one person's trajectory showed best fit with a linear time trend (VP 2) and one person's trajectory best fit with a cubic time trend (VP 8). All other patients did not show any linear trend in their trajectory of Subjective Vitality.

Indicators of critical instability

Multilevel models were estimated to determine whether critical slowing down in daily Subjective Vitality or daily perceived symptom severity predicted significant changes in trait Subjective Vitality or depressive symptoms. No significant interaction of the autocorrelation and outcome for each time series was found ($p > .05$). Furthermore, no significant correlation was found between complexity (max-mean) in the time series of daily Subjective Vitality and symptom severity and improvement in trait Subjective Vitality or depressive symptoms following psychotherapy.

4.4 Discussion

This study explored daily changes in Subjective Vitality, vagal modulation, physical activity and basic psychological need fulfillment over the course of a residential psychotherapy in depressive inpatients. Trait Subjective Vitality significantly increased from pre- to post treatment levels whereas depressive symptoms significantly decreased. Trait Subjective Vitality significantly differed from a healthy control group before but not after treatment. No significant changes were found in average vagal modulation and the average amount of physical activity from pre-to post-treatment.

Dynamic network analysis revealed positive associations between daily Subjective Vitality, vagal modulation, physical activity and feelings of competence, autonomy

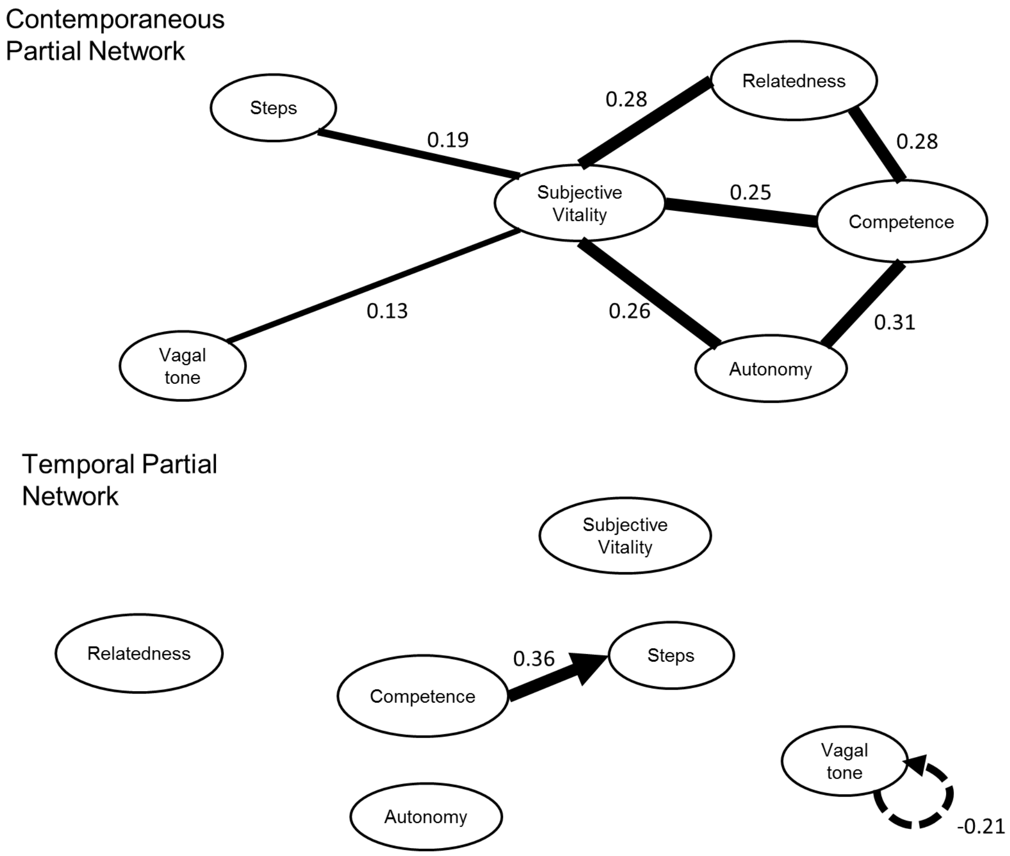

Figure 4.2. Estimated temporal (t-1) and contemporaneous partial correlation networks for Subjective Vitality, vagal tone (lnHF), steps and basic psychological needs (competence, relatedness, autonomy). Solid lines indicate a significant positive partial association on the same day. Arrows indicate significant partial predictive power of the lag 1 variable (t-1) on the target variable on the following day (t). Solid arrows indicate a positive association, dotted arrows a negative association.

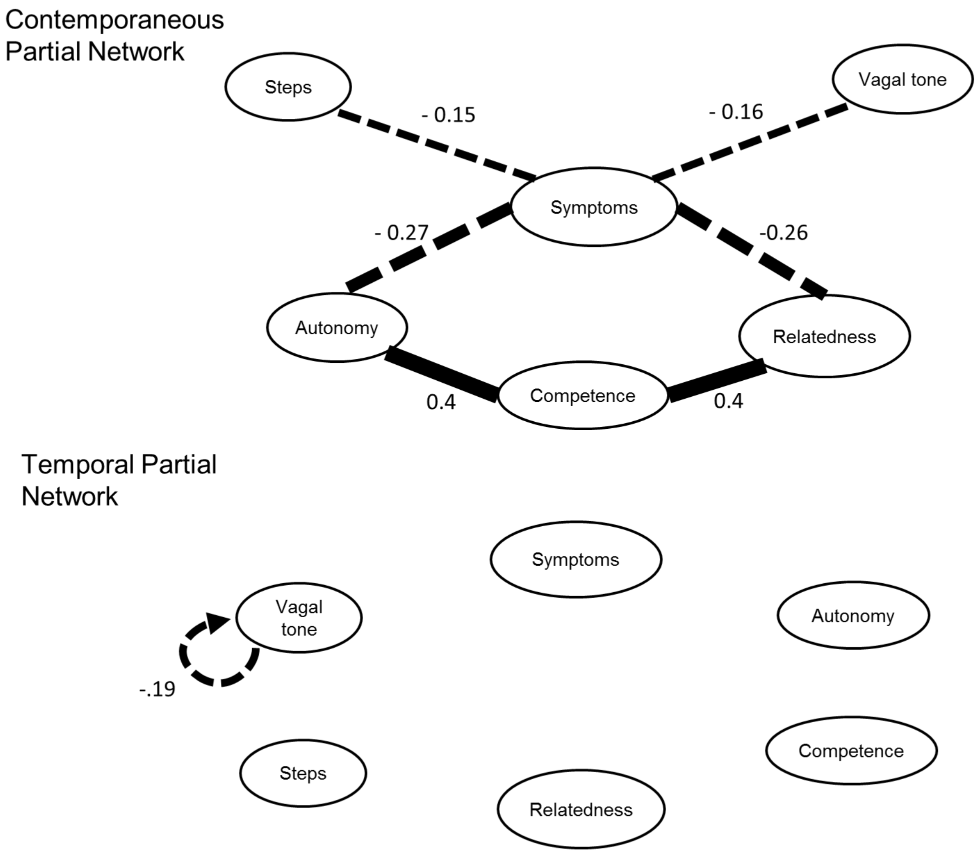

Figure 4.3. Estimated temporal (t-1) and contemporaneous partial correlation networks for perceived symptom severity, vagal tone (lnHF), steps and basic psychological needs (competence, relatedness, autonomy). Solid lines indicate a significant positive association on the same day. Dotted lines indicate a significant negative partial correlation on the same day. Arrows indicate a significant partial predictive power of the lag 1 variable (t-1) onto the target variable on the following day (t). Dotted arrows indicate a negative association.

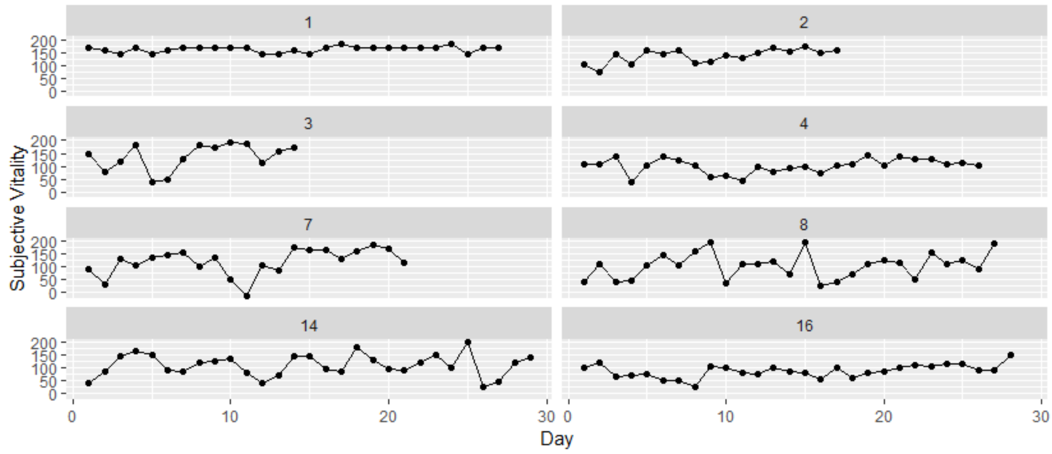

Figure 4.4. Daily trajectories of Subjective Vitality in each Patient. Box numbers indicate subject number.

and relatedness. Feelings of competence were predictive of physical activity on the coming day. Symptoms correlated negatively with vagal tone, physical activity, feelings of autonomy and feelings of relatedness on the same day.

No significant indications were found for associations of critical slowing down and increased complexity in the time-series of state Subjective Vitality and trait changes in outcome. Only one individual displayed a trajectory of Subjective Vitality that could be modeled by a continuous linear increase over time.

Vitality - a Dynamic Network Perspective

The associations found for the contemporaneous networks confirmed assumptions about Subjective Vitality as a conjunctive marker of organismic health (Ryan & Deci, 2008). The positive associations found between daily satisfaction of the needs for competence, relatedness and autonomy and Subjective Vitality confirm findings from healthy samples (Kanning & Hansen, 2016; Reis et al., 2000) in a clinical setting. The three needs also resemble factors linked to the general effectiveness of psychotherapy, namely: therapeutic relationship (relatedness), self-efficacy (competence) and sensation of control (autonomy) (Wampold, 2015). Furthermore, findings are in line with intervention studies that found a positive relationship between Subjective Vitality and physical activity (Duda et al., 2014; Solberg et al., 2012) and findings of a positive relationship between physical activity and positive affect over time (Curtiss et al., 2019; Kanning & Hansen, 2016; Stavrakakis et al., 2015; Sudeck et al., 2018). The positive association between vagal tone and Subjective Vitality in the contemporaneous network confirmed findings of an association between higher aggregated activated positive affect and increased vagal tone (Schwerdtfeger &

Gerteis, 2014). A high structural similarity with the contemporaneous symptom network confirms Subjective Vitality's role as a daily marker of health.

The temporal networks attained in this study yielded few significant relationships over time. "Null-associations" compared to the contemporaneous networks may be another sign for non-linear changes during psychotherapy (Schiepek & Strunk, 2010) especially with regard to the experiential level (e.g., Subjective Vitality, symptoms, psychological needs). In comparison, the self-association found for vagal tone over time highlights potentially different degrees in stability between different indicators of health (Kemp & Quintana, 2013). Perceived competence predicted physical activity on the following day which is in line with associations between competence and physical activity (Sudeck et al., 2018). Overall, great caution should be exerted in the interpretation on the specific relationships between variables due to the small sample size and relatively few observations per subject for this methodology. However, the findings allow for further deduction of specific hypotheses and highlight the interactive nature of Subjective Vitality as a marker of health. On a more general level, the study extends the network approach from psychopathology (Borsboom & Cramer, 2013) to the area of health and well-being and demonstrates how inclusion of distinct layers in the human system (physiology, experience, needs, behavior) may lead to valuable insights regarding changes and cause of effect in interventions over time.

Changes in Trait Markers

The findings in this study indicate that levels of trait Subjective Vitality can be significantly raised during a residential psychotherapy in depressive inpatients. This confirms findings of long-term changes in trait Subjective Vitality following interventions in non-clinical samples (Duda et al., 2014; Solberg et al., 2012) and the effectiveness of psychotherapy regarding changes of a key symptom in depression (Fried et al., 2016; Munder et al., 2019).

No significant changes from pre- to post-treatment levels were found for vagal tone in this study. The mean values attained for parasympathetic activity in this study were in the range of norm values for healthy controls reported by Shaffer and Ginsberg (2017). Based on the exploratory sample size, a large effect size of 0.9 would have been required to reach significance at an alpha-level of .05 which is above the medium effect size reported in the meta-analysis by Kemp et al. (2010). Hence, the present sample size does not allow a final conclusion on the question if levels of vagal tone were not significantly reduced or patient levels had already improved as early gains prior to the inclusion to the study (Hartmann et al., 2019).

Mean physical activity did not change significantly from pre- to post levels in the patient sample; a significant difference remained to the healthy controls. Correlational analysis in the pooled sample showed that trait Subjective Vitality was higher and depressive symptoms lower in people with a higher step count. These results are in line with the fact that the reported mean values of steps per day in the patient sample at both times where below levels associated with an active lifestyle and improved health (D. R. Bassett et al., 2017). Interventions of physical activity were offered but voluntary in the clinic's therapy schedule, hence step count likely resembled individual's habitual physical activity. Adding to prior research (Schuch, Vancampfort, Richards, et al., 2016) this finding underlines the potential of physical activity as one component in the treatment of depression and the necessity of a specific promotion if to exploit this additional resource.

Complex System Trajectories

The individual trajectories of daily Subjective Vitality in this study are in line with findings of non-incremental changes in state variables over the cause of psychotherapy (Schiepek et al., 2014). Only one subject displayed a trajectory that could be explained by a linear incremental trend. Furthermore, we could not confirm associations between indicators of transitions such as critical slowing down and local increase of complexity and changes in trait Subjective Vitality or depression. Among the exploratory sample size that could have prevented significant findings, it is important to note that critical slowing down is no prerequisite for change (van de Leemput et al., 2014). On the same note, Schiepek et al. (2014) did find significant associations of increase in complexity with general symptom change but not change in specific symptoms. Hence, further studies are needed to explore the depths of complex-system transition indicators as predictors of change in psychological outcomes.

Limitations and Future Directions

Due to the exploratory sample size of the study, various limitations need to be considered in the interpretation of the present results. With a small sample size and limited number of observations per subject, inferences to a general population are limited. Patients were included in this study up to ten days upon their arrival in the institution; hence, substantial improvement and change during this time may not have been detected and considered in the analysis. No time-series data was collected for the healthy control group in this study. As some studies have reported differences in network structures between clinical and non-clinical samples (Curtiss et al., 2019; Stavrakakis et al., 2015), future studies are needed to confirm and compare the present findings with networks from healthy controls. On a methodological level, multivariate dynamic network analysis is still in its infancy; certain estimation procedures are not yet implemented and certain methodological problems are not yet addressed (Epskamp et al., 2016) which, in consideration, could have led to different results.

4.5 Conclusion

This study highlights how tracking bio-psycho-behavioral layers in an individual over time may advance our understanding of the dynamic interactions underlying human health. Furthermore, results support the role of Subjective Vitality as an important trait and state marker of organismic well-being. Trait changes of Subjective Vitality were found among a dynamic association of daily Subjective Vitality with basic psychological need satisfaction, physical activity and vagal modulation in depressed inpatients over the course of a residential psychotherapy. Analysis of the change trajectories in daily Subjective Vitality indicated that a linear incremental description of this process may not be adequate. Overall, the study highlights the potential of a dynamic network approach towards human health and Subjective Vitality as a key candidate for interventions regarding the improvement of organismic well-being.

Summary of Results

Chapter 1

Chapter 1 established a valid and reliable instrument to measure vitality by self-report in German-speaking populations. The psychometric characteristics of a 5-, 6- and 7-item version of the Subjective Vitality Scale in German (SVS-G) were comparable to their international counterparts. Negative associations between trait Subjective Vitality and measures of depression, anxiety, somatic symptoms and fatigue were replicated confirming findings from previous studies. Positive associations were found with constructs of vigor, life satisfaction and the amount of hours spent on leisure activities per week. The degree of basic psychological need satisfaction from experiences of competence, relatedness and autonomy predicted individual proportions of variance in trait Subjective Vitality. The second study in Chapter 1 used a randomized control trial design and found state Subjective Vitality significantly increased following a 15 minute brisk walk and a strength-exploring interview. This was not the case for a neutral control condition. Overall, chapter 1 provides the methodological grounds to measure vitality reliably on the level of self-report and in subsequent studies on the physiological correlates of Subjective Vitality.

Chapter 2

Chapter 2 compared patterns of RSFC in healthy subjects with high and regular levels of trait Subjective Vitality. The measurement focused on posterior cortical areas comprising the DMN and neighboring brain areas. A network comprising parts of the DMN and central nodes in the primary and secondary somatosensory cortex showed significantly higher connectivity in high-vital than in regular-vital individuals. The network was specific for trait Subjective Vitality and different from a network resulting for the related well-being measure of flourishing. The difference in RSFC between high- and regular-vital subjects explained a significant share of variance in the RSFC difference between high- and regular-flourishers; the opposite was not the case. High- and regular-vital subjects did not differ regarding their degree of spontaneous self-referential thought (mind-wandering, state rumination), general mental activity (OTP), trait rumination or depressive symptomatology. None of the variables explained a significant amount of variance in the difference of RSFC regarding trait Subjective Vitality. In comparison, high-flourishers showed significantly more mind-wandering, less trait rumination and less depressive symptomatology than regular-flourishers. These differences explained a significant amount of variance in the difference of RSFC between high- and regular-flourishing subjects. Overall, chapter 2 found a specific pattern of RSFC in posterior cortical areas, including parts of the DMN and the primary/secondary somatosensory cortex, as a significant physiological correlate of trait Subjective Vitality.

Chapter 3

Chapter 3 examined changes in state Subjective Vitality and parameters of HRV before, during and after the practice of Qi Gong. Increases in state Subjective Vitality during Qi Gong were accompanied by a moderate physiological activation (reduction in HFpower/vagal tone, increase in HR) in all practitioners. Experienced Chinese practitioners showed signs for a positive association between state Subjective Vitality and spline-interpolated cardiac coherence (corrected for exercise); a state associated with positive mood and mental relaxation. Visual inspection of the trajectory of R-R intervals indicated that a synchronized pattern of ANS up-and down regulation during the practice of Qi Gong may drive this effect. The phenomenological state of Subjective Vitality was further clarified via positive associations with attentional focus, feelings of increased body sensation and activation, pleasantness, calmness and Qi sensation. All findings were significant in the overall sample and with regard to changes in HRV, less pronounced in German Qi Gong amateurs than in Chinese Qi Gong professionals. Age, Qi Gong experience and Qi Gong specific beliefs exerted a significant influence on the results.

Chapter 4

Chapter 4 assessed changes in daily Subjective Vitality and levels of resting state vagal tone (HFpower) among depressive inpatients over residential psychotherapy. Ratings of Subjective Vitality for the present day were positively associated with resting state vagal tone, the satisfaction of basic psychological needs for competence, relatedness and autonomy, and habitual physical activity. An opposite pattern of associations for the same day was found when replacing daily Subjective Vitality with individual symptom intensity. No associations were found for daily Subjective Vitality, resting state vagal tone and the other variables between days. From the start to the end of therapy, trait Subjective Vitality significantly increased in depressive inpatients. At the time of discharge the patients' levels of trait Subjective Vitality and resting state vagal tone did not differ from that of healthy controls. In one out of eight subjects, the trajectory of daily ratings of Subjective Vitality followed a linear, incremental trend.

General Discussion

The goal of the following discussion is to review and integrate the findings presented by returning to the three general questions posed in the introduction:

1. How can the everyday phenomenon of vitality be measured?
2. What is the relationship between the subjective experience of energy and vitality and objective physiological correlates of vitality?
3. What is the relevance of a concept such as vitality in the present landscape of health and science?

Firstly, I will discuss and link the findings from chapter 1-4 to summarize the approaches taken towards the measurement of vitality (Question 1). I will do so by focusing on the self-report measure of Subjective Vitality as a trait, as a state and on daily levels. Linking the concept of Subjective Vitality to question 2, I will review the findings of its physiological correlates and integrate these into the outline of a psychophysiological model of vitality (Question 2). The aim of the model is to connect the present findings with findings from related areas and highlight points of entry for future research. In a third step, I will turn to the question of relevance regarding the present findings in the wider scientific context (Question 3). Subjective Vitality and its physiological correlates will be discussed in the light of their contribution to the three perspectives that inspired this dissertation: The field of positive psychology, the role of the body in psychology and the potential of lay theories for science. Using these contexts, the concept of Subjective Vitality, including its physiological correlates, will be evaluated as a marker of organismic well-being. Ideas for future research and limitations will be discussed prior to the conclusion of the dissertation.

Vitality Measured by Self-report – a Starting Point

One approach to the everyday phenomenon of vitality in this dissertation was to examine its measurability via self-report. In chapter 1, I described the development of a German version of the Subjective Vitality scale (Ryan & Frederick, 1997) and showed that this measure is valid and reliable. The wording of items such as "I feel vital and alive" (Item 1) or "I feel energized" (Item 7) is close if not identical to the lay phrases and descriptions of people quoted at the beginning of the present work. This observation, together with the validity and reliability of the scale analysis in chapter 1, implies that people do not describe their state using phrases of "vitality and energy" arbitrarily. Instead, the results of chapter 1 indicate that these lay descriptions reliably map onto a general (trait) and situation-specific (state) phenomenological experience in people, which is captured by the Subjective Vitality scale.

Furthermore, the findings from chapter 1 confirm previous results that Subjective Vitality is associated with a person's mental and physical health (Ryan & Bernstein, 2004; Ryan & Frederick, 1997). The concept is responsive to interventions focused on somatic (walking) and psychological factors (psychological need fulfillment) (Passarelli, 2015; Ryan & Frederick, 1997; Thøgersen-Ntoumani et al., 2014), which makes Subjective Vitality a promising candidate for future studies regarding the role of somatic processes in psychological phenomena (Seligman, 2008; Tschacher & Pfammatter, 2016).

Subjective Vitality's double association with measures of "well-being" (e.g., vigor and life satisfaction) and "ill-being" (e.g., depression, anxiety, fatigue) furthermore indicates, that the concept captures a major range on the spectrum of health. This includes aspects beyond the "absence of disease and infirmity" (World Health Organization, 1948, p. 1). For example, the positive correlation between trait Subjective Vitality and life satisfaction remains (r_p = .44, $p < .001$) even after controlling for status of depression, anxiety, somatic symptoms and fatigue. Subjective Vitality as a measure of health seems to include dimensions associated with ill-being and well-being that are increasingly acknowledged as independent entities (Insel et al., 2010; Keyes, 2002; Lukat et al., 2016).

Furthermore, despite a positive correlation and an overlap in item wording with the vigor subscale of the Profile of Moods Scale (e.g., "alert", "energetic"; Lorr & McNair, 1971), Subjective Vitality seems to capture more than these aspects. Conditions assumed to increase levels of Subjective Vitality, such as basic psychological need satisfaction of competence, autonomy and relatedness, predict Subjective Vitality beyond the shared variance with vigor (e.g., for competence r_p = .42, $p < .001$). One hypothesis based on physiological studies (see section on physiology) is that the items of vigor mainly cover an *motoric activation* aspect (e.g., "energetic", "vigorous", "lively") of vitality, whereas a different system in the human body accounts for *arousal from perceptual input* (Kuhl, 2009; Pribram & McGuinness, 1975). In order to rate one's own Subjective Vitality, people intuitively draw on both dimensions (R. Thayer, 1978).

At the level of self-report, chapter 1 confirmed Subjective Vitality as a comprehensive indicator of positive health, linked to lay conceptions of vitality and sensitive to somatic and psychological processes. The following sections discuss if these findings can be extended to the physiological correlates examined in relation to Subjective Vitality.

A Physiological Correlate of Trait Subjective Vitality

RSFC in the DMN

In chapter 2, people who reported high levels of trait Subjective Vitality displayed a different pattern of RSFC, compared to people who reported regular levels of trait Subjective Vitality. Both groups were free of any known mental disorder or physical disease. The difference could not be explained by self-referential thoughts during the measurement (mind-wandering, rumination, spontaneous thoughts), trait rumination, high levels of psycho-social functioning (flourishing) or degree of subclinical depressive symptoms. Results from chapter 1 suggest that the self-report measure of Subjective Vitality as a trait captures aspects of health beyond the absence of malicious states - chapter 2 indicates a physiological parallel for this on the level of resting state functional connectivity.

The physiological correlate used in chapter 2 was RSFC in the DMN and neighboring brain areas. As outlined in the introduction, the DMN displays links to the general mode of being, sense of self and health status in a person (Buckner et al., 2008; Raichle, 2015). The findings from chapter 2 suggest that the patterns of default activity in the DMN are specific in people with high levels of trait Subjective Vitality. Specific to the extent that, the patterns differ from those among subjects high in the correlated measure of flourishing. Furthermore, these differences are not explained by the degree of subclinical mental illness (depressive symptoms) in the subject. The results from chapter 2 demonstrate on a physiological level what chapter 1 indicates on a self-report level: trait Subjective Vitality has explanatory power beyond the status of disease in a person and may therefore, also physiologically, capture an additional dimension of health (Cuthbert & Insel, 2013; Keyes, 2002; Lukat et al., 2016).

The differences in RSFC around the DMN were not reducible to state or trait differences in higher mental processes of self-referential thought. Chapter 2 therefore confirmed the DMN's role as a network of interest in the understanding of pleasant subjective experiences (Kringelbach & Berridge, 2017), however, the presumed explanatory mechanism, self-referential thought, did not explain the different activation pattern in high-vital subjects. For flourishing, self-referential thought did have explanatory power, which suggests that further analysis of network patterns in the pleasure system (Berridge & Kringelbach, 2015) and the DMN are a promising path to explore physiological differences between measures of well-being.

Specific Nodes

The appearance of specific nodes in the attained networks of high-vital participants offers some hypotheses on the link between physiology and trait Subjective Vitality. As suggested in the general introduction, differences in coupling between the DMN and other brain areas can be linked to differences in lasting periods of arousal (episodes of depression vs. mania; Martino et al., 2016). The centrality of nodes in the primary and secondary somatosensory cortex found in the networks of high-vital subjects is in line with such findings. Also, the sensitivity of trait Subjective Vitality to somatic symptoms (chapter 1) and physical interventions (chapter 1, 3 and 4) points towards a specific role of the somatosensory system in trait Subjective Vitality. Previous studies link the areas found in chapter 2 with the unconscious representations of feelings and peripheral-physiological activity (Anders, Birbaumer, et al., 2004; Anders, Lotze, et al., 2004), as well as feelings of ownership and identification with one's own body (Aspell et al., 2012; Blanke, 2012). Whether subjects high in trait Subjective Vitality are in fact more aware of their feelings or whether the perception of physiological processes form a larger part of their conscious sense of self, should be the subject of future studies. The hypothesis is supported by findings of diminished interoception in conditions negatively related to trait Subjective Vitality such as mental illness (Khalsa et al., 2018).

The relationship between physical activity and trait Subjective Vitality was not an explicit focus in chapter 2 but, high-vital subjects also reported significantly more exercise engagement per week. Chapter 1, 3 and 4 indicate that physical activity can lead to higher levels of state and daily Subjective Vitality. How these activities, if pursued on a regular basis, translate into measurable changes of trait Subjective Vitality and potential changes in patterns of RSFC merits future study. In the context of this dissertation it can be concluded that trait Subjective Vitality seems to have a specific physiological correlate at the level of RSFC, which indicates a specific role of somatosensory processes in high-vital subjects. Regular exercise may play an important role regarding the formation of trait Subjective Vitality, which links the findings from chapter 2 to exercise interventions used in the previous and the following chapters.

A Physiological Correlate of State Subjective Vitality

HRV and Qi Gong

Chapter 3 described how participants' subjective state and standard parameters of HRV (Malik, 1996; Shaffer et al., 2014) changed over the course of the mind-body exercise Qi Gong. Following the walking intervention in chapter 1, Qi Gong was chosen due to its explicit assumption of an increase in the flow of Qi, in western contexts often equated with vitality (Chow et al., 2012). From a bio-medical point of view, the assumed mechanism underlying the health benefits of Qi Gong, is a form of psychophysiological regulation (Chow et al., 2012; Ng & Tsang, 2009) via the alignment of breath, posture and imagery during practice (Chen & Liu, 2010). Besides using this integrated intervention to assess changes in state Subjective Vitality linked to HRV, we hoped to clarify phenomenological aspects of the concept via additional measures of self-report and the recruitment of practitioners in two different cultural contexts (China and Germany).

Two main findings emerged from the study in chapter 3: during the practice of Qi Gong, all participants showed a moderate activation in their ANS linked to increased levels of Subjective Vitality. The level of activation ($\approx$ 80-90bpm) was equivalent to what one would expect during a brisk walk (chapter 1). Furthermore, this finding was independent of age, Qi Gong experience, beliefs about the effects of Qi Gong and cultural background. The second finding was an increase in overall modulation (SDNN) and cardiac coherence (coherence, SPcoherence) of varying degrees between participants. These findings are tied to the different oscillating rhythms in the human body (Tiller et al., 1996). During a normal state of wakefulness, the heart beat, breath and constriction of blood vessels are interdependent, however, not strictly coupled. Under some circumstances, these rhythms synchronize (Lehrer et al., 2009; Tiller et al., 1996) and subjects enter a state of cardiac coherence, which is associated with positive emotions and feelings of relaxation (McCraty et al., 1995; McCraty & Zayas, 2014). Almost all Chinese participants examined in chapter 3 showed signs of cardiac coherence (corrected for exercise) during Qi Gong. A marginal significant link to state Subjective Vitality was found (r = -.46, p = .056) and a stronger link to the culturally familiar concept of Qi sensation (r = -.51, p = .03). Furthermore, experienced practitioners in the Chinese sample displayed stronger effects. Hence, increases in state Subjective Vitality during Qi Gong seem to co-vary with a general mechanism of moderate physiological activation (in all practitioners) and a specific mechanism of coherence attainment, previously associated with relaxation, in more experienced practitioners.

Is the state of Subjective Vitality during Qi Gong being activated and relaxed at the same time? The theory supports this contention (T. Liu, 2016; Payne & Crane-Godreau, 2013; Ryan & Bernstein, 2004) backed up by evidence from neuroscience (Henz & Schöllhorn, 2018). Our phenomenological findings support this assumption too: Qi Gong practitioners reported a high level of calmness and concurrent feelings of body activation. This notion links back to the discussion from chapter 1 on the difference between Subjective Vitality and vigor in that vigor is lacking the component of calmness integrated by Thayer in his concept of calm energy (R. Thayer, 1978, 2001). Calm energy has been associated with Subjective Vitality (Ryan & Bernstein, 2004). On the physiological level, chapter 3 shows how cardiac coherence may be one measure to demonstrate the degree of calmness that indicates that energy is in the zone of self-availability (Ryan & Frederick, 1997). Moderate general ANS activation and mental relaxation flowing from micro-regulation explain why states of mere arousal or thoughts that threaten to overwhelm the self are usually not conceived as vital states (Ryan & Bernstein, 2004). A distinction between a peripheral-physiological arousal/activation component (energy) and a mental calmness component (sense of self-availability) may also explain how situations like skiing down-hill and observing a flower in the garden can both increase one's subjective state of vitality: by emphasizing different components grounded in the physiology of our body (Pribram & McGuinness, 1975).

Qi and State Subjective Vitality

So far, the findings show a complex relationship between distinct physiological mechanisms, their interaction during Qi Gong and state Subjective Vitality. These complexities potentially explain why the concept of Qi has never properly been operationalized in physiological terms (Kaptchuk, 2014). In chapter 3, participants' reports of a sensation of Qi closely followed ratings of Subjective Vitality during periods of exercise and rest. The link between coherence and sensation of Qi in the Chinese participants was stronger than the marginal significant link to state Subjective Vitality. Besides the multi-layers of cultural meaning attached to the concept (Kaptchuk, 2014), physiologically it might only be approachable as an emergent phenomenon (Haken & Schiepek, 2006). Similar to Subjective Vitality, the sensation of Qi may rise from the interplay of different components in the organism forming a moment to moment subjective experience. Based on this experience, chapter 3 demonstrates a phenomenological and physiological overlap between the concept of Subjective Vitality and the concept of Qi. The finding further emphasizes the importance of lay theories as Qi is used as colloquially in Chinese daily life language as vitality in Western countries.

How these moment to moment experiences, for instance, during Qi Gong, translate into a trait-like disposition of Subjective Vitality is an open question. However, studies of Qi Gong show that, frequent practice leads to improved body perception (T. Liu, 2013; Sze et al., 2010) and positive mood (F. Wang et al., 2013). In this way, patterns of RSFC, as described in chapter 2, could stem from a learned association between one's self and the frequent, pleasant, body-focused state of Subjective Vitality. Whether experienced Qi Gong practitioners show higher levels of trait Subjective Vitality should be the subject of future studies. However, how physical activity relates to changes in daily levels of Subjective Vitality has been examined in chapter 4.

A Physiological Correlate of Daily Subjective Vitality

Regenerative Capacity in the ANS

Chapter 4 looked at how daily ratings of Subjective Vitality, over a period of several weeks, correlated with resting state vagal tone in the evening, and a variety of other health-related variables. In order to explore associations between the different variables, a sample, likely to display variation and improvement over time, was examined: depressive in-patients receiving residential psychotherapy.

With regard to the link between physiology and Subjective Vitality, one major finding emerged: Increases in daily Subjective Vitality were associated with higher resting state vagal tone on the same day. At first glance, this finding is at odds with the negative association between vagal tone and state Subjective Vitality during Qi Gong from chapter 3. However, the results are in line with the different roles of vagal tone as a measure of ANS reactivity and as a resting state measure (Kemp et al., 2017). The findings in chapter 4 indicate that people whose ANS is able to relax well during a resting state condition (high vagal tone), rate their daily Subjective Vitality as higher and vice versa. Compared to state Subjective Vitality's link to a moderately activated, regulated ANS state (chapter 3), daily Subjective Vitality seems to be associated with the ANS' automatic capacity to transitions into a state of regeneration. Furthermore, daily Subjective Vitality and resting state vagal tone did not significantly predict each other between days. Both variables seem to be sensitive mostly to experiences on the same day which is in line with previous findings (Kemp et al., 2017; Reis et al., 2000; Ryan, Bernstein, et al., 2010; Sheldon et al., 1996). This claim is further supported by the fact that seven out of eight patients did not display an incremental trajectory in daily Subjective Vitality despite a significant improvement in trait Subjective Vitality over therapy. How daily levels of Subjective Vitality and resting state vagal tone transition into a change of trait Subjective Vitality warrants further research.

ANS Modulators: Physical Activity and Psychological Needs

Chapter 4 also demonstrated a significant association between daily Subjective Vitality and habitual physical activity on the same day. The reason we did not find an association between physical activity and resting state vagal tone in the evening, may be the influence of time on the effect of physical activity. Only physical activity early in the day leads to more parasympathetic activity at night (Gladwell et al., 2016; Yamanaka et al., 2015). The finding indicates how physical activity may trigger the organism towards a more pronounced cycle of activation and regeneration over the day. Whether daily Subjective Vitality serves as important marker and even mediator in that cycle should be subject of future studies.

An additional factor relevant for the modulation of this cycle could be psychological need fulfillment. Chapter 4 confirmed the association between psychological need satisfaction (chapter 1) and Subjective Vitality on a day-to-day basis in a clinical setting. When patients' reported more competence, relatedness, or autonomy, they also reported more Subjective Vitality. A connection to resting state vagal tone exists via daily Subjective Vitality. Taken together, daily Subjective Vitality may serve as an interface and aggregate for beneficial modulating effects on the ANS. Future studies should evaluate daily Subjective Vitality as an accessible parameter for the quality of a health-inducing cycle linked to energy expenditure and regeneration processes in the ANS.

An implicit knowledge and daily experience of "vitality-cycles" may be one reason for the continuous use of vitality as a concept in the public. The two items used to measure daily Subjective Vitality ("Today I felt vital and alive", "Today I had energy and spirit") are in fact close to the lay notion of vitality outlined at the beginning.

The results of chapter 4 point towards the intricate nature of Subjective Vitality at the intersection of somatic and psychological factors. Daily Subjective Vitality qualifies as a marker of general health, sensitive to changes in psychological and physical processes, while capturing dynamics between behavior, subjective experience and physiology. Overall, daily Subjective Vitality seems to be a predictive marker of a healthy day. The findings add to the "empirical record" justifying why single items exploring vitality or energy have been included in long as well as brief versions of nation-wide general health surveys (Butler & Kern, 2016; Power et al., 1999; Schmidt et al., 2005; Ware & Sherbourne, 1992).

A Psychophysiological Model of Vitality

In the following section, I summarize the results and outline a psychophysiological model of vitality. The model links results regarding Subjective Vitality and objective physiological correlates to findings from personality research, neurophysiology and health. The model's aim is to provide a framework of orientation regarding the psychophysiology of everyday vitality and highlight promising entry points for future investigations.

Basic Vitality and the Brain Stem

I start with the hypothesis that despite the original author's finding of a unidimensional structure for the Subjective Vitality scale (Ryan & Frederick, 1997), confirmed in chapter 1, different systems in the human organism are likely to contribute to the subjective experience of energy and vitality. A brain structure with a clear link to the fundamental state of wakefulness (e.g., Item 6: "I nearly always feel awake and alert") is the ascending reticular activation system (ARAS) evolving from the brain stem. The ARAS is associated with sleep, different degrees of wakefulness and modulation of cortical excitability (Kinomura et al., 1996; M. D. Schwartz & Kilduff, 2015). The fluctuation of feelings of energy and alertness over the course of a day and between day and night (Monk, 1989) is potentially under strong influence of the ARAS (J. R. Schwartz & Roth, 2008; M. D. Schwartz & Kilduff, 2015). In interaction with higher brain centers, often involving the hypothalamus, the ARAS contributes to the regulation of general arousal/activation necessary to process information from the environment and behaviorally respond in adaptive ways. This interaction of brain systems involving the ARAS has been demonstrated for phenomena with a face-valid link to the subjective experience of energy and vitality such as the sleep-wake cycle (M. D. Schwartz & Kilduff, 2015), immune status (McCusker & Kelley, 2013), blood sugar level (Williams & Elmquist, 2012) or general homeostatic condition of the organism (Critchley & Harrison, 2013). Furthermore, the principle of modulating feedback loops between higher order (e.g., hypothalamus) and lower order physiological centers (e.g., brain stem) indicated here is a prominent feature of how different systems in the organism's physiological hierarchy interact to regulate fundamental states of organismic well-being (Jackson, 1887; Porges, 2009). Subjective Vitality's two sub-components, energy and sense of self-availability (Ryan & Frederick, 1997), may find a physiological correspondence in this principle, which will be further elaborated in the following sections.

General Activation Revisited

It has been known for some time that, the source of general arousal/activation linked to the ARAS can be further subdivided in relation to its anatomical pathways (Derryberry & Tucker, 1990). From a simplified perspective, the general arousal/activation system can be separated into a system linked to *arousal* as "phasic physiological responses to input" and *activation* as "tonic physiological readiness to respond" (Pribram & McGuinness, 1975). In other words, two different neural circuits are responsible for response to perceptual input and motor readiness (D. M. Tucker & Williamson, 1984). Item 4 ("I have energy and spirit") and Item 6 ("I nearly always feel alert and awake") of the Subjective Vitality scale may relate to these different neurophysiological subsystems.

Furthermore, on the level of neuro-modulators, the authors relate arousal (response to input) to noradrenalin and activation (motor readiness) to dopamine. Note that Thayer's concept of calm energy (R. Thayer, 1978, 2012), an equivalent to state Subjective Vitality (Ryan & Bernstein, 2004) in chapter 3, emerges from low arousal (high subjective calmness) and high activation (high energy) (Kuhl, 2009). Thus, our findings of a simultaneous increase in general activation (indexed by an increase in HR and reduction in vagal tone) and mental calmness (indexed by SPcoherence) following Qi Gong, suggest a specific involvement of the neuro-modulators dopamine and noradrenalin in state Subjective Vitality. The pattern of rhythmic up-and down-regulation in the ANS (indexed by an increase in SDNN and SPcoherence) during Qi Gong may keep the organism in an optimum balance of motor activation and arousal from perceptual input experienced as state Subjective Vitality.

The two dimensions of arousal from perceptual input and motor activation also offer a possible explanation for similar increases of state Subjective Vitality following distinct activities such as mindfulness (K. Brown & Ryan, 2003; Visser et al., 2015) and exercise (Solberg et al., 2012). Mindfulness emphasizes the regulation of arousal from perceptual input, whereas physical exercise emphasizes motor activation; both can lead to increases in Subjective Vitality. The distinction also explains everyday comments from the introduction: Feeling vital and alive when one has been exposed to the wild Norwegian landscape may encompass a similar experiential quality as a salsa dance experience with different physiological correlates linked to motoric activation and arousal from perceptual input.

The Pleasure System – a Point of Connection

The involvement of dopamine as neuro-modulator might also explain why Subjective Vitality as a trait and state is associated with positive valence (e.g., chapter 1) (Wise & Rompre, 1989). Dopamine plays a central role in the *pleasure system* (Berridge & Kringelbach, 2015). A closer look links this finding back to activation or "motor readiness" (D. M. Tucker & Williamson, 1984) as recent evidence suggests, that within the pleasure cycle, dopamine is associated with a wanting component that increases action tendencies towards incentive stimuli (Kringelbach & Berridge, 2017). This fits with the description of Subjective Vitality as a sense of energy and enthusiasm (Ryan & Bernstein, 2004) compared to non-activated states, such as contentment or life satisfaction (Ryan, Weinstein, et al., 2010).

The role of dopamine in pleasure and motor activation (Kringelbach & Berridge, 2017) might also explain why physical activity works well as an intervention to increase levels of Subjective Vitality (Duda et al., 2014; Shepherd et al., 2015; Solberg et al., 2012). Physical activity is a common theme in vital people and situations, apparent in the examples from the beginning and confirmed in chapter 1, 3 and 4. Besides a range of other physiological changes, acute bouts of exercise have been shown to increase dopamine levels causing changes in mood, especially the induction of positive, high-general activation states (Basso & Suzuki, 2017).

Psychological Need Satisfaction

Yet, the experience of Subjective Vitality following exercise varies depending on non-physical factors such as basic psychological need fulfillment (Duda et al., 2014; Gagne, 2003; Ryan et al., 2009; Teixiera et al., 2012). We can assume that a modulating feedback loop between higher level brain systems and lower level structures in the pleasure system offers a potential explanation for that effect (Kuhl, 2009).

Studies investigating the neurophysiology of basic psychological need fulfillment highlight three structures as a potential match for this hypothesis: the striatum, the anterior insular cortex and certain regions in the prefrontal cortex (Reeve & Lee, 2019). The authors link the striatum, which comprises part of the aforementioned pleasure system, to reward processing, the anterior insula to the subjective experience of reward and the ventromedial prefrontal cortex (vmPFC) to failure-monitoring of psychological need satisfaction.

Intermediate Summary

To summarize the basic assumptions of the model at this point: Fundamental states of vitality depend on structures centered in the brain stem (e.g., ARAS). Different sub-branches of the ARAS linked to motoric activation or arousal from perceptual input contribute to vitality. The neuro-modulators dopamine and noradrenaline play a distinct role in these sub-branches linked to vitality. The pleasure system (Berridge & Kringelbach, 2015) connects basal factors influencing a person's vitality such as sleep, absence of disease or movement and higher-order factors such as psychological need fulfillment. The anterior insular cortex likely plays an important role in the subjective experience of vitality: it "does for psychological needs what it does for physical needs" (Reeve & Lee, 2019, p.108), that is the integration of internal information into a subjective experience (Craig, 2009; Damasio, 1996). Lastly, the vmPFC's role in need thwarting conditions (Murayama et al., 2013) highlights the potential role of modulating feedback loops in the psychophysiology of Subjective Vitality. Components within the physiological hierarchy may correspond with the sub-components of energy and self-availability in Subjective Vitality.

Higher Cortical Processes, Regulation and the Self

With regard to the physiology of Subjective Vitality, the vmPFC seems like a crucial area of further elaboration. It is associated with reward monitoring (Berridge & Kringelbach, 2015), regulation capacity (Lane et al., 2009; J. Thayer et al., 2012) and structures linked to the notion of self (Damasio, 1996; Northoff et al., 2006; Raichle, 2015). The present dissertation did not examine vmPFC activity directly, however the area plays a key role in the regulation of HRV (J. Thayer et al., 2012) and the DMN (Raichle, 2015), hence both physiological correlates applied here.

HRV and regulative capacity of the self

Ryan and Frederick (1997) state that energy (provided e.g. by the ARAS) must be felt as available to the self in order to experience Subjective Vitality. Accumulating evidence suggests that high levels of HRV or vagal tone indicate top-down appraisal, mediated by the capacity of the vmPFC to inhibit subcortical pathways (Kemp et al., 2017). In the conceptualization of Subjective Vitality, activity in the vmPFC might then correspond to the self's ongoing evaluation and the capacity to regulate (subcortical) energy. HRV in turn acts as a marker of the degree to which the self evaluates energy as being available and manageable. J. Thayer et al. (2012) observes that HRV may provide an index of the degree to which the brain's integrative system for adaptive regulation provides flexible control over periphery. The positive association between resting state HRV and daily Subjective Vitality in Chapter 4 is in line with these assumptions.

Energy and the self - a continuous feedback loop

Moreover, our findings from Chapter 3 support theoretical assumptions that the connection between prefrontal cortical areas and peripheral physiology is not a one-way street but a feedback loop. This feedback loop can also be influenced bottom-up and increase the self's capacity to regulate, such as during the practice of mind-body exercise (Mather & Thayer, 2018). In this sense, the self and energy are not independent sub-components but, the self regulates energy and energy feeds into the capacity of the self to regulate. It is important to note the difference between acute changes in HRV, which reflect autonomic responsiveness to the current activity (chapter 3) and resting state HRV, which may be the aggregate multiple psychological moments(Chapter 4; Kemp et al., 2017). Findings from this dissertation indicate how resting state vagal tone could be the physiological correlate of daily ratings of Subjective Vitality as it measures both components, energy and availability to the self. State Subjective Vitality in contrast, and its association with general arousal/activation linked to an acute decrease in vagal tone may be more an online indicator of energy expenditure with SPcoherence as a sufficient, however not a necessary boundary condition for the self's felt capacity to regulate energy.

Trait components

Research on trait reports of basic psychological needs satisfaction, a condition associated with high trait Subjective Vitality (Ryan, Bernstein, et al., 2010; Sheldon et al., 1996), found increased responsiveness in the striatum and anterior insula to conditions of basic psychological need fulfillment. Furthermore, trait reports of basic psychological need satisfaction are associated with increased structural volume in the anterior insula (Reeve & Lee, 2019). In line with our proposed model, participants also showed greater involvement of medial prefrontal areas during self-related decision conflicts (Di Domenico et al., 2013). Raichle (2015, p. 439) notes "the emotional state of the subject has a direct effect on the activity level in the vmPFC component of the DMN" offering a link between the responses in trait Subjective Vitality to the notion of self in trait Subjective Vitality.

In Chapter 2, we reported specific patterns of DMN related activity comprising nodes in the somatosensory cortices, which is in line with the central role of visceral feedback for decision processes and the construction of lower and higher levels of self based on current physiological state (Alcaro et al., 2017; Damasio, 1996; Schaefer & Northoff, 2017). Fluctuations in Subjective Vitality may be reflected in the balance of different resting state networks (Martino et al., 2016) which in turn relate to different levels of resting state vagal tone (C. Chang et al., 2013). Overall, trait Subjective Vitality seems to be associated with a physiological pattern that is indicative of high responsiveness to positive feelings (striatum), a strong representation of internal bodily states (anterior insula), to the degree that they form part of the conscious notion of self (DMN), and a stable capacity for the effective regulation of external and internal stimuli (vmPFC).

Model Summary

The last section intended to combine findings of the present dissertation with evidence from the fields of personality, neurophysiology and health into the outline of a simplified psychophysiological model of vitality. Besides the introduction to different components, the section highlights the role of feedback loops within the neurophysiological hierarchy and their importance for a more refined understanding of the physiology behind the subjective experience of energy and vitality. The assumption of feedback dynamics within a physiological hierarchy offers new ways to explore the relationship between energy and the sense of self-availability in Subjective Vitality. The NBS approach in chapter 2 and the dynamic time series in chapter 4 tried to pay tribute to the fact that Subjective Vitality and its physiological correlates interact as a dynamic complex feedback system, whose processing over time we are only beginning to understand. Furthermore, the present model highlights how research on the physiology of Subjective Vitality may contribute to our understanding of health and well-being in a person. Subjective Vitality has potential as an organismic marker of well-being, which will be the topic of the following section.

Subjective Vitality – an Organismic Marker of Well-Being?

In the following section I want to evaluate the present findings regarding their contribution to the scientific context described in the introduction (Question 3). I will do so by addressing the three scientific areas this dissertation aims to contribute to. All three serve to evaluate the concept of Subjective Vitality as a marker of organismic well-being. The three scientific areas and their respective goals were 1) Positive psychology and the exploration of Subjective Vitality's capacity to measure health beyond the absence of disease and infirmity 2) Physiology and the role of the body: exploring positive divergence on the physiological level and Subjective Vitality's sensitivity to physical and psychological processes 3) Lay concepts and science: how do lay concepts of vitality stand in regard to the validated concept of Subjective Vitality and its physiological correlates?

Ryan and Frederick hypothesized Subjective Vitality could reflect *organismic well-being* (Ryan & Frederick, 1997). Their criterion was that of a covariation with psychological and physiological factors. The first criterion in the following evaluation will therefore be sensitivity to somatic and psychological factors (*psychosomatic sensitivity*). Based on the above-mentioned areas of science, I extend the conceptualization of organismic well-being with the criteria of *positive divergence* (health beyond the absence of disease and infirmity) and *practical potential* (predictor for general health and closeness to lay concepts).

Positive Divergence

The previous chapters have demonstrated positive divergence in a variety of ways. Chapter 1 found trait Subjective Vitality as a predictor of life satisfaction beyond the explanatory power of any clinical symptoms. Chapter 2 showed how trait Subjective Vitality differentiates otherwise healthy subjects on a dimension of well-being that is grounded in the variation of brain activity. Chapter 1 and 3 demonstrated how state Subjective Vitality can be increased in already healthy subjects and how state Subjective Vitality is linked to the beneficial state of cardiac coherence. Turning to the other end of the health spectrum, Chapter 1 and 4 showed that levels of trait and state Subjective Vitality are sensitive to mental and physical health constraints and increase following improvement in such conditions. All of these findings imply that Subjective Vitality holds the capacity to measure health on a dimension that goes beyond the absence of disease and infirmity.

Psychosomatic Sensitivity

The link between Subjective Vitality and cardiac coherence induced via the mind-body exercise of Qi Gong lends support to Ryan and Frederick's original criterion of organismic well-being. Chapter 1, 3 and 4 showed that one's state and daily levels of Subjective Vitality can be changed by physical as well as psychological interventions. Furthermore, mental and somatic disease states interact with trait Subjective Vitality (Chapter 1). Chapter 2, 3 and 4 showed that state, trait and daily Subjective Vitality are linked to central and peripheral-physiological correlates. Overall, the findings from chapter 2, 3 and 4 as well as the elaboration of the psychophysiological model of vitality in the last section suggest Subjective Vitality's sensitivity to physiological and psychological processes.

Practical Potential

As discussed previously, the items of the Subjective Vitality scale seem very close to a lay person's everyday understanding of vitality. As Chapter 4 showed, the two items "Today I felt vital and alive" and "Today, I had energy and spirit" appeared sufficient on a daily basis to infer something about the physiological state (vagal tone), conditions contributing to health improvement (psychological needs), health supportive behavior (physical activity) and symptom severity in a person. These relationships are bi-directional and highlight Subjective Vitality as an easy to grasp interface to an ongoing psycho-physio-behavioral feedback cycle of health. In fact, the findings of this dissertation are in line with energy as a marker of general health (Stewart et al., 1992) and the power of a single general health item to predict vagal tone and other physiological indicators (Jarczok et al., 2015). An item such as "In general I feel vital and alive" may be an even more powerful predictor than a general health item, because it also covers positive divergence on the dimension of health. From a practical perspective, Subjective Vitality seems to be a concept close to people's lay understanding of vitality and a promising predictor of general health.

Time Reference

Additionally, chapter 1-4 indicate that the concept of Subjective Vitality exhibits distinct characteristics when applied with regard to a trait, state or daily reference frame of time. Depending on the frame of reference, the concept is linked to moderate ANS activation and coherence following micro-regulation (state), ANS regenerative capacity (daily), and distinct patterns of resting state neurophysiological co-activation (trait). Overall, the concept of Subjective Vitality meets every criterion to be regarded as a marker of organismic well-being under the defined criteria.

Research on Vitality – the Road Ahead

An Integrated Vitality Intervention

After summarizing the present findings, integrating them into a psychophysiological framework, and evaluating Subjective Vitality as a marker of organismic well-being, the following section highlights questions and future directions of research.

Following the first exploration of Subjective Vitality and its physiological correlates, one important next step would be to track physiological and subjective state changes following a specific "vitality intervention". Using the parameters from this dissertation, the main goal would be to monitor changes and separate general from specific effects on the phenomenological as well as the physiological level. Especially with regard to the similar phenomenological effects of physical and psychological interventions (e.g., physical activity and SEI), it would be interesting to examine differences and overlap in the underlying physiology. One arm of the study could contain a physical intervention program, one arm a psychological intervention program and one arm a mixed program in order to disentangle the different effects. Daily monitoring of changes, such as in chapter 4, combined with pre-and post measures of RSFC (chapter 2) would allow to explore the open question if and how trait changes in Subjective Vitality linked to physiological changes come about. Are they different depending on the focus of intervention (e.g., somatic vs. psychological)? The observed change and differences in, for example, RSFC and vagal tone over time, would allow testing and extending the findings of this dissertation. Programs entailing positive psychological (Rashid, 2015) as well as exercise interventions (Schuch, Vancampfort, Rosenbaum, et al., 2016) have yielded promising results that might be further enhanced by their integration into a vitality intervention.

Use as a Preventive Marker, Priming and Vitality Profiles

Subjective Vitality has demonstrated qualities as a marker of organismic well-being and predictor of general health. A second development would be to further explore this potential by using Subjective Vitality as a preventive marker in epidemiological studies. As a marker of organismic well-being, Subjective Vitality might be capable to inform health developments on a psychological and physiological level prior to the rise of symptoms. In such way, the concept could improve monitoring in particular risk groups, enhance the effectiveness of prevention programs and contribute to well-being and proactive health behavior in institutional settings.

Based on the influence of lay theories on people's health behavior (Hauser et al., 2017), it would be interesting to assess a "vitality" vs. an "antidepression" intervention with similar content. Research indicates that the mental models and metaphors people use to describe diseases and their treatment, influence their attitudes and behavior (Forstmann et al., 2012; Hauser et al., 2017). Hence, a treatment that "cures depression" could have different effects from a treatment that "increases vitality" even if people underwent the same intervention. Research in that direction would further illuminate the potential and use of lay concepts in the promotion of health behavior.

Linked to the last paragraph, another interesting perspective would be to examine people's individual conceptualizations of "vitality" and the individual factors that contribute to their Subjective Vitality. Personalized medicine is a fast-growing field and the study of individual vitality-profiles would be a promising step in the development of more effective interventions. Furthermore, the continuous stream of data, available from the widespread use of smart devices (e.g, the quantified-self movement), offers opportunities to study the dynamic interaction of factors from these profiles over time.

Vitality in Groups and Organizations

Expanding on the individual approach, it is unclear how Subjective Vitality in one individual influences Subjective Vitality in others around them. Anecdotally, people such as Dylan from the first pages of this dissertation have a "contagious" energy. We do not know whether this phenomenon is grounded in physiological processes, and if so, which ones. Similarly, following Seligman's call for positive institutions (Seligman & Csikszentmihalyi, 2000), the Subjective Vitality of teams and organization has not been assessed. Some authors have started to view organizations from an organismic perspective (Laloux, 2015) and it would be interesting to determine whether a marker of organismic well-being could also be applied to whole organizations.

The main topic of this dissertation was to explore ways of measuring vitality and its physiological correlates. The last section outlined various questions arising from the present findings. Their investigation in the future may serve individuals, institutions and organizations alike.

Limitations

The following section outlines some general limitations of the present dissertation. The limitations of the single studies are discussed in detail at the end of each chapter and will not be repeated here.

At the outset of the dissertation, few studies existed on the physiology of Subjective Vitality. Hence, much of the work described above is of an exploratory nature. The work at hand tried to balance statistical rigor and explorative breadth under the aim of marking a range of solid entry points for future investigations. For example, the detection of changes in aggregated levels of resting state vagal tone with a small effect size (Chapter 4) in patients would have required a sample size of $n > 200$. A sample of such size was not feasible for the project. The longitudinal design and the statistical approach applied (Epskamp et al., 2016) allowed for an exploration of the relationship between daily Subjective Vitality and resting state vagal tone with a much smaller sample size. However, due to the recent development of the approach, at the time of writing, no implemented procedures or validated guidelines existed regarding specific sample size requirements. Hence, the sample size and data point cut-off values used in chapter 4 were based on rules of thumb and single power simulation studies (personal communication with S. Epskamp).

Overall, the dissertation contains one validation study (chapter 1) and three studies (chapter 2-4) with sample sizes large enough to detect medium effect sizes at a significance level of $\alpha = .05$. Small effects may not have been detected in the applied study designs, which limits the completeness of the present conclusions.

Furthermore, in the exploration of correlations from chapter 3 no correction for multiple testing was applied and chapter 4 used an OR rule in the search for within-day correlations. Both approaches increase the chance of a false positive result (α error) and decrease the chance of miss (β error). Hence, the results should be interpreted with caution and taken as starting point for future confirmatory studies.

Apart from this general limitation one specific limitation is the fact, that the first author of all studies was not blind to the purpose of study and had a personal interest in the topic. This is a serious constraint long known in empirical research (Rosenthal & Rubin, 1978). However, in this case, it was the only way to explore a topic off the beaten track of current scientific interests with limited resources. To further validate the present findings replications and future studies are needed with rigorous experimental procedures conducted by independent researchers.

Conclusion

Freud had his take on vitality, the ancient Chinese had their take on vitality and the scientists of the industrial revolution as well (G. Brown, 1999). Aristotle's prescription to increase vital pneuma sounds similar to what is being offered by the vitality-industry today, so what is the contribution of this dissertation that we did not know 2000 years ago?

As outlined in the beginning, the topic of vitality seems to have lost none of its relevance to people in their everyday lives. Apart from the public interest, the subjective experience of energy and vitality correlates with a range of desired outcomes on the individual, organizational and societal level. Expanding on the ancient Chinese, who were masters of the pulse diagnosis, and Galen, who had a great intuition about the body-mind connection, the present dissertation used HRV and RSFC to resume the exploration of physiological correlates underlying self-reported Subjective Vitality. The results offer hypotheses on how Niobe's level of vitality might differ from that of ordinary people and what working in the garden has in common with the sensation conferred by an accelerating BMW X7.

The idea of vitalism, an underlying force to explain living phenomena, started to decline in the 17th century (Westfall, 1977), because mechanistic physical models offered better and testable explanations for the phenomena of the world. However, evidence has started to accumulate that vitalism was correct in one of its central assumptions: Macro-level phenomena are hard to explain by exclusively mechanistic accounts of its sub-components (Haken & Schiepek, 2006; Mayer, 2010). Concepts such as *organicity* and *emergence* (Malaterre, 2013; Mayer, 2010) have re-entered the scientific discourse that share with vitalism a non-reductionist perspective linking complex lower level processes with the simplicity of a macro-level phenomenon. One way to describe Subjective Vitality and its relation to physiological correlates is as an emergent phenomenon (Haken & Schiepek, 2006). The subjective experience of vitality rises from and feeds back into the dynamic interplay of psycho-physiological-behavioral layers in the organism. It is the result and cause of a process that reflects the dynamics of organismic well-being in the self (Deci & Ryan, 1991): in the form of calm activation in state Subjective Vitality, as regenerative capacity and energy available to the self in daily Subjective Vitality and as a body-focused self-representation in trait Subjective Vitality. The present research demonstrates how the concept of vitality may become approachable from a perspective of emergence and contribute to the understanding of the interacting psycho-physiological layers that constitute health.

As we are venturing into the age of Big Data, the amount of accessible information challenges traditional approaches to derive meaning from information. Theories and new methods of analysis are needed to guide this endeavor. Methodological approaches such as NBS, complexity theory and multilevel dynamic time-series, as used in this dissertation, are first steps to access these streams of information. At the same time, a person seems to be capable of integrating all their "organismic information" into a single rating of Subjective Vitality. The present dissertation tried to look at the complex physiological, as well as the Gestalt-like subjective end of vitality. For a long time, the concept has carried a notion of reductionist simplification (Westfall, 1977). This dissertation tried to take a different approach by linking the psycho-physiological complexities of human health with the subjective experience of a phenomenon relevant in people's everyday lives.

Four studies investigated ways to measure vitality via self-report and its physiological correlates using the indicators of HRV and RSFC. The dissertation introduced a psychophysiological model of vitality and evaluated the concept of Subjective Vitality as a marker of organismic well-being. As a whole, the work provides one bio-medically empirical perspective on the everyday phenomenon of vitality. I wish it may serve as an inspiration for future studies on the people and situations that make us feel vital and alive.

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Appendix A

Supplementary Material Chapter 2

Mind-activity and Subjective Experience

Spontaneous mind-activity and subjective experience during the measurement of RSFC was captured using an open-thought protocol. Following the 7min resting state measurement, all subjects received a blank page of paper to write down their sensations, thoughts, feelings and subjective experiences during the measurement. The OTP was screened and categorized by two independent raters to assess qualitative measures of the process during resting state according to qualitative methods: The forms were first analyzed and categories of experiential content were set and defined until saturation was reached. Second, the most common categories were used to categorize self-report forms by two independent raters. Furthermore, the raters evaluated emotional tone (positive, negative, mixed, neutral) and level of arousal (calm, aroused) of the thought protocol. For the final analysis, the ratings of the two independent raters for each OTP were discussed if deviating and integrated in a final single rating. The result of the analysis are displayed in Table A.1.

Table A.1. Categories of the OTP, example and % occurrence in overall sample

	Category of subjective experience	Example	%
1	*Mind-wandering*: The subject expressed to be in a relaxed mood and let his mind flow in an unconstrained way without any focus on a particular subject	"I relaxed and let my mind flow."	25
2	*Rumination*: The subject expressed a repetitive stressful style of thinking about an unfinished concern that leads to the urge of suppressing the inner experience.	"I thought about a stressful meeting I had at work, which made me nervous, so I tried to distract myself from that memory."	5
3	*Focus on body sensations*: The subject expressed an attentional focus on their body/breath	"I focused on my breathing."	35
4	*Mindfulness/Relaxation training*: The subject expressed to be in a mindful state (detachment from cognition, concentration on breathing with detached mind) or 3 to perform some kind of relaxation technique (e.g. progressive muscle	"I focused on my breathing and watched my mind in a detached way."	12
5	*Suppression*: The subject expressed withdrawal from or suppression of unpleasant inner experiences	"I felt the weight (of the NIRS cab) on my head and tried to think about something else"	12
6	*Boredom*: The subject expressed that the resting-state was boring	"I felt bored"	5
7	*Making future plans*: The subject expressed thoughts about things they will do	"I thought about what I would eat for dinner and decided to eat pizza."	60
8	*Thinking about the measurement*: The subject expressed thoughts about the given instructions or how their data might look like	"I wondered what he (the experimenter) would see"	30
9	*Fight against fatigue*: The subject expressed feeling sleepy or trying not to fall asleep	"I felt tired"	32
10	*Thinking about the duration of the measurement*:	"I was wondering how much time had already passed"	21
11	*Listening to external noise*: The person reported focusing on external sounds	"I heard the noise of the NIRS machine"	5

Emotional tone	Example	%
Positive	"I was thinking about my last surf vacation and how good it felt to be in the water."	47
Negative	"I felt upset about my PhD thesis and kept thinking how much I still needed to write"	18
Neutral	"Then I did some mental calculus and repeated the movements I had learned yesterday	17
Mixed	"The lecture was very boring but in the evening I met my friends which was nice"	13
Aroused	"I was feeling excited"	11
Calm	"I felt quiet and didn't think much"	48

Appendix B

Supplementary Material Chapter 3

National subsample characteristics

The Chinese and the German sample deviated significantly from each other with regard to age, $t_{40} = 7.45$ $p < .001$, and level of education, $\mathcal{X}^2_2 = 12.35$ $p = .002$. The mean age in the German sample was 56.4 years (SD =12.4) and 28.8 years (SD =11.6) in the Chinese sample. Chinese participants indicated marginally significant more occasions of practice per week, $t_{40} = 1.92$, p =.063 and on average a longer duration of practice $t_{27.6} = 3.38$, p =.002 whereas German participants reported a significantly longer experience in average years of Qi Gong practice, $t_{36.5} = 3.56$, p =.001. As a result, the sub-samples did not differ in the estimated overall time spent on Qi Gong practice ($p > .10$). The subsamples showed no difference in the belief in the existence and power of Qi. A significant difference between groups was found for the belief in the accessibility of Qi to scientific investigation, $t_{40} = 2.628$, $p = .012$ with the Chinese sample believing more strongly in this aspect. Chinese participants differed significantly from German participants in the duration of both

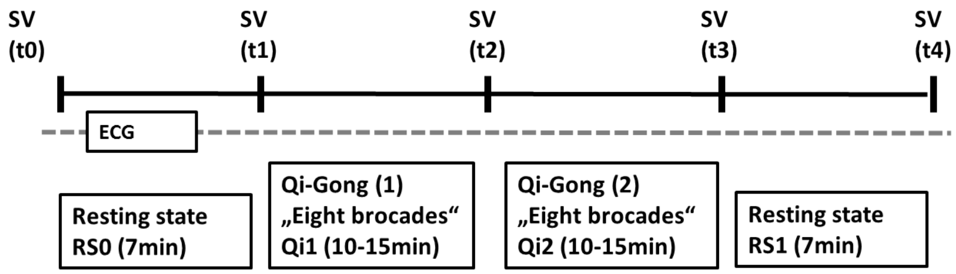

Figure B.1. Study procedure of chapter 3 with measurement points for momentary subjective state assessment (t0 - t4), type of activity (Resting state, Qi Gong) and time estimates exercise rounds, $t_{40} = 5.18$, $p < .001/t_{40} = 5.34$, $p <.001$ with the Chinese sample taking an average of 3:19min/3:03min longer.

Qi Gong specific beliefs: Scale generation

To assess Qi Gong specific beliefs in the two national samples, nine items were derived from discussions of the first author with various Qi Gong teachers based on public available training materials. In order to explore the structure of Qi Gong specific belief items, we conducted a principal axis factor and reliability analysis on the nine belief items. We expected statistical dependency so an oblique rotation (direct oblimin) was used. An initial principal axis factor analysis on the nine items was run that yielded a three factor solution with Eigenvalues > 1 and together explained 62.5% of the variance. The Kaiser-Meyer-Olkin measure verified the adequacy of the sample size for the analysis, KM = 0.66. The screeplot was ambiguous and showed inflexions that would justify a one-, two-, and three-factor solution. Reliability analysis for Factor 1 (Item 1,2,5,8) yielded a Cronbach's alpha of $\alpha = .27$. Item 8 ("Qi Gong mainly serves the purpose of disease prevention") was the only item whose exclusion indicated a reliability improvement. Omitting item 8 increased reliability of Factor 1 to a Cronbach's alpha of $\alpha = .71$. Factor 2 yielded a Cronbach's alpha of $\alpha = .65$. Item 9 ("Qi Gong can accelerate the process of recovery from a disease") was the only item to comprise a single factor and was therefore omitted. SI Table B.1 shows the rotated factor loadings, Eigenvalues, explained % of variance and α of the original items.

We repeated the principal factor analysis with oblique rotation after omission of item 8 and 9 which yielded a two-factor solution with Eigenvalues > 1 that together explained 58.2% of the variance. All items had their highest loading on the same factor as in the prior analysis (SI Table B.2). Factor 1 comprised the items 3,4,6 (reversed) and 7 which focus on the nature of Qi and it's accessibility to scientific investigation. Factor 2 comprised items 1,2 and 5 (reversed) with a focus on the existence of Qi. Due to the original order of the items the factors are described in a different order in the orginal paper. Factor 1 is "Belief in Qi" (Item 1: "During Qi Gong I can feel my Qi"; Item 2: "I don't believe in the existence of Qi (r: to be recoded)"; Item 3: "There is something like Qi, however science has yet to succeed in measuring it"). Factor 2 is "Belief in the scientific investigatability of Qi" (Item1: "There is a scientific explanation for Qi"; Item 2: "Qi is something that can't be explained by science (r: to be recoded)"; Item 3: "Qi is a sensation which emerges during the alignment of movement, attention and breath"; Item 4: "Qi Gong as intervention is also capable of curing serious disease, such as cancer"). The items were translated into Chinese and German using a backward-forward approach in a similar manner as the subjective state items (SI Table B.3).

Table B.1. Results of the factor of all Qi belief items

No	Item	Rotated Factor Loadings Factor 1	 Factor 2	 Factor 3
5	I don't believe in the existence of Qi (r)	**0.79**	0.06	-0.03
2	During Qi Gong, I can feel my Qi	**0.76**	0.03	0.1
1	There is something like Qi, however, science has yet to succeed in measuring it	**0.4**	0.18	0.1
8	Qi Gong mainly serves the purpose of disease prevention	**-0.38**	0.26	0.01
9	Qi Gong can accelerate the process of recovery from a disease	0.04	**0.98**	-0.08
4	There is a scientific explanation for Qi	-0.03	0.19	**0.95**
7	Qi Gong as intervention is also capable of curing serious disease, such as cancer	-0.02	-0.16	**0.58**
6	Qi is something that can't be explained by science (r)	0.26	-0.05	**0.41**
3	Qi is a sensation which emerges during the alignment of movement, attention and breath	0.15	0.21	**0.24**
	Eigenvalues	3.16	1.4	1.1
	% of variance	35.16	15.58	11.8
	Cronbach's α	.27	-	.65

Table B.2. Results of the Confirmatory Factor Analysis for the Qi Belief items

No	Item	Factor 1	Factor 2
5	I don't believe in the existence of Qi (r)	**-0.98**	-0.15
2	During Qi Gong, I can feel my Qi	**-0.58**	0.21
1	There is something like Qi, however, science has yet to succeed in measuring it	**-0.43**	0.12
4	There is a scientific explanation for Qi	0.03	**0.94**
7	Qi Gong as intervention is also capable of curing serious disease, such as cancer	0.04	**0.55**
6	Qi is something that can't be explained by science (r)	-0.26	**0.4**
3	Qi is a sensation which emerges during the alignment of movement, attention and breath	-0.05	**0.35**
	Eigenvalues	1.02	3.06
	% of explained variance	14.56	43.67
	Cronbach's α	.71	.65

Table B.3. Items for the assessment of Qi belief in Englisch, Chinese and German

EN	CN	GER
Belief in Qi		
During Qi Gong I can feel my Qi	在练健身气功的时候我能感觉到气	Während Qi Gong kann ich mein Qi spüren
I don't believe in the existence of Qi (r)	我不相信气是存在的(r)	Ich glaube nicht, das es so etwas wie Qi gibt (r)
There is something like Qi, however, science has yet to succeed in measuring it	气是存在的，只是现在的科学还无法测量它	Es gibt so etwas wie Qi, die Wissenschaft konnte es nur noch nicht messen
Belief in the scientific investigatability of Qi		
There is a scientific explanation for Qi	气这种现象是有可以用科学解释的	Für Qi gibt es eine naturwissenschaftliche Erklärung
Qi is something that can't be explained by science (r)	气这种现象是科学无法解释的(r)	Qi ist etwas, dass sich nicht wissenschaftlich erklären lässt (r)
Qi is a sensation which emerges during the alignment of movement, attention and breath	气是一种感知，气随着运动、注意力和呼吸的一体化而形成的整体	Qi ist eine Wahrnehmung, welche bei der Integration Bewegung, Aufmerksamkeit und Atem in eine Einheit entsteht
Qi Gong as intervention is also capable of curing serious disease, such as cancer	健身气功可以作为一个独立的干预，包括严重的疾病，如癌症治疗	Qi Gong als eigenständige Intervention kann auch schwere Krankheiten, wie z.B. Krebs heilen
Excluded Items		
Qi Gong mainly serves the purpose of disease prevention	健身气功，主要用于疾病的预防	Qi Gong dient vor allem der Vorbeugung von Krankheiten
Qi Gong can accelerate the process of recovery from a disease	健身气功，主要用于疾病的预防	Qi Gong kann den Heilungsprozess nach einer Krankheit beschleunigen

Table B.4. German and Chinese translation of all items used as subjective state measures in chapter 3

No	**EN**	**CN**	**GER**
1	I feel alive and vital	我感觉很有活力和生命力	Ich fühle mich vital und lebendig
2	I have energy and spirit	我很有能量、动力和热情	Ich habe Energie und Elan
3	I feel calm	我内心安定	Ich fühle ich mich ruhig
4	I feel pleasure in my body	我身体感觉舒适	Ich habe ich ein angenehmes Körpergefühl
5	My attention is focused	我的注意力集中	Meine Aufmerksamkeit ist fokussiert
6	I can sense my own body	我能感觉到自己的身体	Ich spüre meinen Körper
7	My body feels activated	我身体感觉活力	Mein Körper fühlt sich aktiviert an
8	I can feel the Qi	我能感觉到气	Ich kann das Qi spüren

Subjective State Change: Details from the Overall Sample

Overall, Subjective Vitality was significantly different between the different measurement points, $F_{(2.76,105.02)} = 19.79$, $p < .001$, partial $\eta^2 = 0.34$. Post-hoc tests revealed that SV significantly increased following the Qi Gong exercise compared to baseline (t0-t3; $p < .001$) and to the end of the resting period (t1-t3; $p < .001$). No significant change was observed during the initial resting period (t0-t1; $p = .223$). SV significantly decreased during the second resting period (t3-t4; $p = .018$) and returned to a level not significantly different from initial baseline (t0-t4; $p = .64$). The changes in SV over the course of the experiment in the overall sample are displayed in SI Figure B.2.

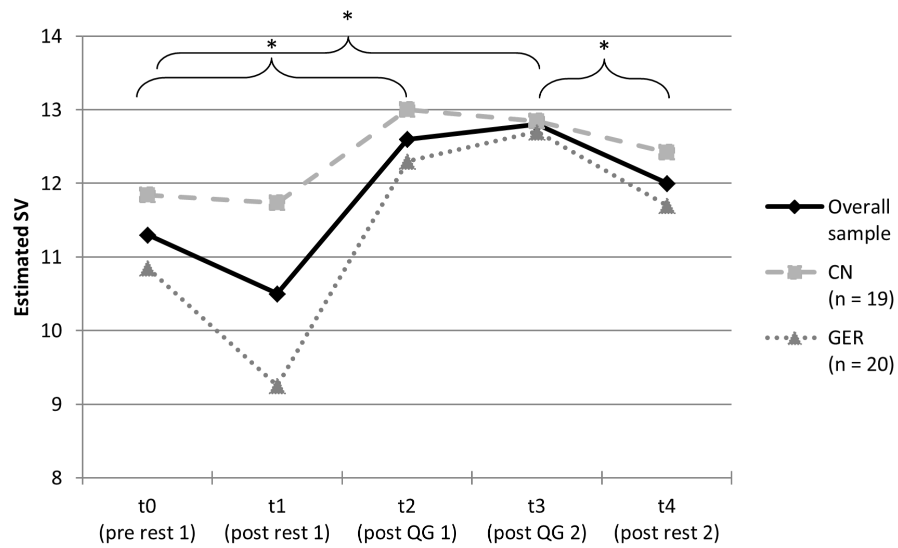

Figure B.2. Estimated state Subjective Vitality for each measurement point (t0 - t4) in the overall Sample and the national subsamples from chapter 3

Repeated measures ANOVA showed that the subjective perception of calmness, $F_{(3.02,114.63)} = 11.58$, $p < .001$, partial $\eta^2 = 0.23$, pleasant body sensations, $F_{(2.12,80.61)} = 11.66$, $p < .001$, partial $\eta^2 = 0.23$, focused attention, $F_{(2.84,107.9)} = 14.38$, $p < .001$, partial $\eta^2 = 0.27$, body awareness $F_{(2.77,105.24)} = 12.66$, $p < .001$, partial $\eta^2 = 0.25$ and perceived body activation, $F_{(2.63,99.96)} = 24.58$, $p < .001$, partial $\eta^2 = 0.39$ significantly changed over the course of the experiment. The variables displayed different patterns of change: Calmness was the only measure that increased during the initial resting period (t0-t1; $p = .002$) and remained at this increased level (t0-t3; $p = .001$) over time until the end of the experiment (t1-t2, t2-t3; $p > .10$; t1-t4; $p = .577$). Pleasant body sensation, focused attention, body awareness and perceived body activation did not change during either resting period (t0-t1, t3-t4; all $p >$ .10) but increased over the course of the Qi Gong exercise compared to baseline (t0-t3; all $p < .002$) and remained at this level (t3-t4; all $p > .05$). The sensation of Qi, $F_{(2.38,88.2)} = 36.40$, $p < .001$, partial $\eta^2 = 0.50$ changed significantly over the course of the experiment. It did not change over the first resting period (t0-t1; $p > .10$) but increased following the Qi Gong exercises (t0-t3, t1-t3; all $p <$. 001). The perception of Qi significantly decreased over the second resting period (t3-t4; all $p < .008$). All subjective state changes with their respective trend direction are displayed in SI Table B.5. The estimated means, standard errors and confidence intervals of all subjective state measures for the overall sample are contained in SI Table B.6.

Subjective State Changes: Analysis in the Chinese and the German Subsample

All subjective state items in their German, Chinese and English translation are contained in Table B.4. The general trend of increase in Subjective Vitality following Qi Gong compared to no changes/decrease during the resting conditions was similar and significant in both national subsamples (SI Figure B.2, SI Table B.5). The German sample showed a tendency of decrease in SV during the resting periods (t0-t1; $p = .095$; t3-t4; $p = .051$) whereas the Chinese sample reached a peak in SV following the first Qi Gong exercise (t0-t2; $p = .015$) with a decrease afterwards (t0-t3; $p = .281$).

For all subjective state variables except pleasant body sensation the two subsamples showed similar changes as in the overall sample (SI Table B.5). Focused attention, body awareness and perceived body activation showed no change over initial rest and significant increase during one or both Qi Gong exercise compared to initial baseline ($p < .05$). Calmness showed a trend for a significant increase during rest in the Chinese (t0-t1; $p = .065$), less so in the German (t0-t1; $p = .115$) subsample and remained on this level. In the Chinese sample pleasant body sensation showed a trend for a significant overall difference over the course of the experiment ($p = .101$). In the German sample pleasant body sensations were significantly higher following Qi Gong (t0-t3; $p = .001$; t1-t3; $p = .015$) and did not change over the second resting period ($p > .10$). All changes and the respective p-values are reported in SI Table B.5. The estimated means, standard errors and 95% confidence intervals for all subjective state variables in the two subsamples are contained in SI Table B.7 and SI Table B.8 .

Participants Excluded from HRV Measurement

In eight participants we found that electrodes had been loosened or displaced during the practice. In two participants the sensor recording only displayed noise. Three

Table B.5. Significant changes in Subjective Vitality and other subjective state variables in the overall and the national subsamples of chapter 3

Overall sample (CN/GER) $N = 39$ ($n = 19/n = 20$)	**Rest 0** (t0-t1)	**Qi Gong** (t0-t3)	**Qi Gong** t1-t3	**Rest** 1 (t3-t4)
Subjective Vitality	○ (○/○) .223 (>.99/.095)	↗ (○/↗) <.001 (.281/.004)	↗ (↗/↗) <.001 (.008/<.001)	↘ (○/○) .018 (>.99/.051)
Calmness	↗ (○/○) .002 (.065/.115)	↗ (○/↗) .001 (.065/.034)	○ (○/○) >.99 (>.99/>.99)	○ (○/○) >.99 (>.99/.493)
Pleasant body sensation	○ (○/○) .163 (.232/>.99)	↗ (○/↗) .002 (.896/.001)	○ (○/↗) .052 (>.99/.015)	○ (○/○) >.99 (>.99/>.99)
Focused attention	○ (○/○) .864 (.073/>.99)	↗(↗/↗) <.001 (.041/.025)	↗ (○/↗) .004 (.419/.039)	○ (○/○) >.99 (.962/>.99)
Body awareness	○ (○/○) >.99 (>.99/>.99)	↗ (↗/↗) <.001 (.034/.031)	↗(○/↗) <.001 (.083/.008)	○ (○/○) >.99 (.15/>.99)
Perceived body activation	○ (○/○) >.99 (>.99/.486)	↗ (↗/↗) <.001 (.014/.001)	↗ (↗/↗) <.001 (.014/<.001)	○ (○/○) .051 (.349/.662)
Sensation of Qi	○ (○/○) .118 (.419/.897)	↗(↗/↗) <.001 (.001/<.001)	↗ (↗/↗) <.001 (.001/.001)	↘ (○/○) .003 (.082/.099)

Table B.6. Estimated means, standard error and 95% CI for subjective state variables in the overall sample over the course of the experiment

Overall sample	T0	SE CI	T1	SE CI	T2	SE CI	T3	SE CI	T4	SE CI
Subjective Vitality	11.3	0.34 [10.6; 12.0]	10.5	0.39 [9.7; 11.2]	12.6	0.27 [12.1; 13.2]	12.8	0.27 [12.2; 13.3]	12.0	0.33 [11.4; 12.8]
Calmness	5.6	0.18 [5.2; 6.0]	6.2	0.14 [6.0; 6.5]	6.1	0.14 [5.8; 6.3]	6.4	0.15 [6.1; 6.7]	6.5	0.13 [6.2; 6.8]
Pleasant body sensation	5.5	0.23 [5.0; 5.9]	5.9	0.21 [5.4; 6.3]	6.3	0.13 [6.0; 6.5]	6.4	0.13 [6.2; 6.7]	6.5	0.13 [6.3; 6.8]
Focused attention	5.6	0.2 [5.2; 6.0]	5.8	0.18 [5.5; 6.2]	6.3	0.12 [6.1; 6.6]	6.4	0.14 [6.2; 6.7]	6.4	0.12 [6.2; 6.6]
Sensing one's own body	5.9	0.16 [5.5; 6.2]	6.0	0.17 [5.6; 6.3]	6.5	0.1 [6.3; 6.7]	6.6	0.12 [6.4; 6.8]	6.5	0.11 [6.3; 6.7]
Perceived body activation	5.1	0.22 [4.7; 5.6]	4.9	0.25 [4.4; 5.4]	6.4	0.11 [6.1; 6.6]	6.5	0.12 [6.3; 6.8]	6.0	0.21 [5.6; 6.4]
Perception of Qi	4.3	0.27 [3.7; 4.8]	4.8	0.27 [4.3; 5.4]	6.0	0.17 [5.7; 6.4]	6.3	0.18 [5.9; 6.7]	5.9	0.18 [5.5; 6.2]

Table B.7. Estimated means, standard error and 95% CI for subjective state variables in the Chinese sample over the course of the experiment

Chinese sample	T0	SE CI	T1	SE CI	T2	SE CI	T3	SE CI	T4	SE CI
Subjective Vitality	11.8	0.4 [11.0; 12.7]	11.7	0.34 [11.0; 12.4]	13.0	0.35 [12.3; 13.8]	12.8	0.31 [12.2; 13.5]	12.4	0.35 [11.7; 13.2]
Calmness	5.9	0.19 [5.5; 6.3]	6.5	0.16 [6.2; 6.9]	6.2	0.23 [5.7; 6.5]	6.5	0.19 [6.1; 6.9]	6.5	0.23 [6.0; 7.0]
Pleasant body sensation	5.7	0.36 [5.0; 6.5]	6.3	0.22 [5.9; 6.8]	6.3	0.2 [5.9; 6.7]	6.5	0.18 [6.1; 6.8]	6.5	0.19 [6.1; 6.9]
Focused attention	5.8	0.26 [5.2; 6.3]	6.2	0.2 [5.8; 6.6]	6.5	0.19 [6.1; 6.9]	6.6	0.17 [6.3; 7.0]	6.4	0.16 [6.0; 6.7]
Sensing one's own body	6.1	0.21 [5.7; 6.6]	6.4	0.16 [6.0; 6.7]	6.7	0.13 [6.4; 7.0]	6.8	0.09 [6.7; 7.0]	6.5	0.18 [6.1; 6.8]
Perceived body activation	5.5	0.3 [4.8; 6.1]	5.7	0.26 [5.1; 6.2]	6.5	0.14 [6.2; 6.8]	6.7	0.13 [6.4; 7.0]	6.2	0.22 [5.7; 6.7]
Perception of Qi	5.1	0.29 [4.5; 5.7]	5.5	0.27 [5.0; 6.1]	6.2	0.27 [5.6; 6.8]	6.4	0.26 [5.8; 6.9]	5.8	0.24 [5.3; 6.3]

Table B.8. Estimated means, standard error and 95% CI for subjective state variables in the German sample over the course of the experiment

German sample	T0	SE CI	T1	SE CI	T2	SE CI	T3	SE CI	T4	SE CI
Subjective Vitality	10.8	0.54 [9.7; 12.0]	9.2	0.58 [8.0; 10.5]	12.3	0.4 [11.5; 13.0]	12.7	0.45 [11.7; 13.6]	11.7	0.56 [10.5; 12.9]
Calmness	5.3	0.3 [4.7; 6.0]	6.0	0.2 [5.6; 6.4]	6.0	0.16 [5.7; 6.3]	6.2	0.22 [5.7; 6.7]	6.5	0.13 [6.3; 6.8]
Pleasant body sensation	5.2	0.3 [4.6; 5.8]	5.4	0.33 [4.8; 6.1]	6.2	0.18 [5.9; 6.6]	6.4	0.18 [6.0; 6.8]	6.5	0.17 [6.1; 6.8]
Focused attention	5.4	0.29 [4.8; 6.0]	5.5	0.28 [4.9; 6.1]	6.2	0.16 [5.9; 6.5]	6.2	0.2 [5.8; 6.7]	6.4	0.15 [6.1; 6.7]
Sensing one's own body	5.6	0.24 [5.1; 6.1]	5.6	0.27 [5.0; 6.2]	6.3	0.15 [6.0; 6.7]	6.4	0.21 [6.0; 6.8]	6.5	0.15 [6.2; 6.9]
Perceived body activation	4.8	0.31 [4.1; 5.4]	4.2	0.35 [3.5; 4.9]	6.2	0.17 [5.8; 6.6]	6.3	0.2 [5.9; 6.8]	5.8	0.34 [5.1; 6.6]
Perception of Qi	3.5	0.36 [2.7; 4.2]	4.1	0.42 [3.2; 5.0]	5.9	0.2 [5.5; 6.3]	6.2	0.27 [5.6; 6.8]	5.9	0.27 [5.3; 6.5]

participants had to be excluded from the analysis of the subjective measures due to missing answers.

HRV Analysis for National Subsamples

Changes of HRV indicators followed a similar trend in the Chinese and German subsample (SI Figure B.3). lnHF and RMSSD showed a tendency to decrease during Qi gong compared to rest whereas lnVLF, SDNN and HR showed an increase during Qi Gong (Table B.10, Table B.11). No significant differences between the resting periods were found (all $p > .10$). The overall effects for lnHF, $F_{(1.3,22.5)} = 25.75$, $p < .001$, partial $\eta^2 = 0.6$, lnVLF, $F_{(1.5,25.8)} = 36.57$, $p < .001$, partial $\eta^2 = 0.68$, RMSSD, $F_{(1.2,20.7)} = 14.81$, $p = .001$, partial $\eta^2 = 0.47$, SDNN, $F_{(1.3,23.1)} = 5.67$, $p = .018$, partial $\eta^2 = 0.25$ and HR, $F_{(1.4,23.2)} = 214.83$, $p < .001$, partial $\eta^2 = 0.93$ were significant and more pronounced in the Chinese sample whereas in the German sample the overall effect was only significant for HR, $F_{(1.6,21.9)} = 177.56$, $p < .001$, partial $\eta^2 = 0.93$ and lnVLF, $F_{(2,25.9)} = 5.34$, $p = .012$, partial $\eta^2 = 0.29$ and lnHf ($p = .103$), RMSSD ($p = .106$) showed a trend for significance.

No sample showed an overall difference in cardiac coherence ($p > .10$). The effect for SPcoherence was only found in the Chinese sample $F_{(1.3,22.3)} = 6.37$, $p = .013$, partial $\eta^2 = 0.27$, whereas in the German sample no overall difference between conditions was found ($p = .57$). The raw data for the overall sample is contained in Table B.9.

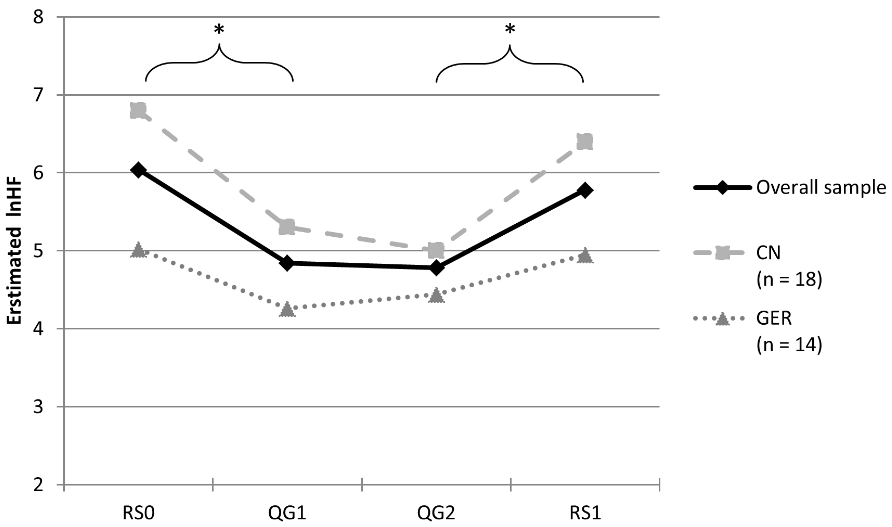

Figure B.3. Estimated natural Logarithm of High-frequency Power (lnHF) for each of the four measurement periods (Rest prior Qi Gong, Qi Gong 1, Qi Gong 2 and Rest post Qi Gong) in the overall sample and the national subsamples

Table B.9. HRV raw data

Overall sample	RS_0 (n=40)	*SD*	Qi_1 (n=36)	*SD*	Qi_2 (n=34)	*SD*	RS_1 (n=37)	*SD*
HF (m^2)	1093	(1820)	212	(262)	214	(283)	966	(1735)
LF (m^2)	1108	(1460)	1890	(2008)	1943	(2038)	877	(1336)
VLF (m^2)	730	(660)	2311	(2042)	2522	(1978)	966	(1204)
lnHF	5.83	(1.69)	4.74	(1.22)	4.78	(1.12)	5.72	(1.66)
lnLF	6.23	(1.35)	6.96	(1.26)	7.01	(1.29)	6.01	(1.27)
lnVLF	6.23	(0.9)	7.35	(0.98)	7.47	(0.98)	6.31	(1.07)
HF (n.u.)	41.62	(23.33)	11.94	(9.7)	11.38	(8.88)	44.52	(25.13)
LF (n.u.)	58.3	(23.39)	88.02	(9.77)	88.57	(8.92)	55.32	(25.23)
Coherence	0.43	(0.35)	0.52	(0.46)	0.48	(0.36)	0.32	(0.26)
Coherence SP	0.87	(0.7)	1.51	(1.87)	1.33	(0.74)	0.65	(0.48)
RMSSD	45.19	(35.81)	22.85	(10.16)	23.38	(10.3)	45.72	(41.28)
SDNN	51.45	(27.24)	64.3	(24.69)	65.83	(23.4)	51.89	(30.48)
SD1	32.02	(25.37)	16.17	(7.19)	16.54	(7.29)	32.38	(29.24)
SD2	64.11	(31.53)	89.28	(34.5)	91.45	(32.76)	64.27	(34.7)
HR	66.76	(9.11)	90.02	(10.03)	91.37	(9.17)	65.98	(8.7)
Total Power (ms^2)	2934	(3110)	4414	(3515)	4681	(3498)	2814	(3258)
Power Peak (0.04Hz-0.4 Hz)	0.13	(0.07)	0.06	(0.02)	0.06	(0.02)	0.15	(0.09)

Table B.10. Estimated mean, standard error and 95% CI of all HRV parameters in the Chinese sample

Chinese sample (n=18)	RS_0	SE CI	Qi_1	SE CI	Qi_2	SE CI	RS_1	SE CI	*p*
lnHF	6.8	0.32 [6.16; 7.5]	5.3	0.2 [4.88; 5.71]	5.0	0.2 [4.63; 5.48]	6.4	0.33 [5.75; 7.12]	<.001*
lnVLF	6.5	0.18 [6.12; 6.88]	8.04	0.13 [7.75; 8.83]	8.07	0.13 [7.8; 8.35]	6.6	0.25 [6.07; 7.13]	<.001*
Coherence	0.39	0.08 [0.21; 0.57]	0.46	0.06 [0.33; 0.6]	0.42	0.07 [0.28; 0.57]	0.24	0.04 [0.15; 0.33]	= .118
Coherence SP	0.61	0.16 [0.27; 0.95]	1.75	0.48 [0.74; 2.75]	1.38	0.12 [1.13; 1.64]	0.4	0.07 [0.26; 0.54]	= .013*
RMSSD	63.99	9.43 [44.1; 83.89]	26.28	1.96 [22.16; 30.41]	24.53	1.51 [21.34; 27.73]	62.43	11.08 [39.04; 85.81]	= .001*
SDNN	63.45	6.75 [49.21; 77.68]	80.79	4.44 [71.43; 90.15]	78.57	4.12 [69.88; 87.25]	60.86	7.97 [44.05; 77.67]	= .018*
HR	62.08	1.64 [58.63; 65.54]	89.48	2.06 [85.13; 93.82]	92.69	2.19 [88.08; 97.31]	63.22	1.64 [59.77; 66.67]	<.001*

Table B.11. Estimated mean, standard error and 95% CI of all HRV parameters in the German sample

German sample (n=14)	RS_0	*SE* *CI*	Qi_1	*SE* *CI*	Qi_2	*SE* *CI*	RS_1	*SE* *CI*	*p*
lnHF	5.02	0.38 [4.2; 5.83]	4.26	0.38 [3.41; 5.11]	4.44	0.38 [3.61; 5.26]	4.95	0.4 [4.08; 5.82]	= .103
lnVLF	5.75	0.27 [5.16; 6.33]	6.52	0.23 [6.02; 7.01]	6.65	0.24 [6.13; 7.16]	5.9	0.26 [5.37; 6.52]	= .012*
Coherence	0.48	0.1 [0.26; 0.7]	0.51	0.11 [0.28; 0.75]	0.59	0.12 [0.32; 0.85]	0.46	0.09 [0.27; 0.65]	= .669
Coherence SP	1.03	0.16 [0.69; 1.37]	0.9	0.42 [0; 1.8]	1.3	0.27 [0.73; 1.9]	0.96	0.15 [0.64; 1.28]	= .57
RMSSD	30.71	6.94 [15.72; 45.71]	18.69	3 [12.21; 25.17]	22.61	3.84 [14.32; 30.9]	28.92	8.1 [11.41; 46.42]	= .106
SDNN	38.96	6.2 [25.56; 52.37]	45.29	4.94 [34.62; 55.97]	49.41	5.83 [36.82; 62.01]	42.98	7.13 [27.56; 58.39]	= .156
HR	72.1	2.62 [66.43; 77.76]	90.34	2.24 [85.5; 95.18]	90.6	2.5 [85.2; 96.0]	69.47	2.79 [63.43; 75.5]	<.001*

Appendix C

Author Contribution

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Appendix D

Eidesstattliche Erklärung

Ich erkläre hiermit, dass ich die zur Promotion eingereichte Arbeit mit dem Titel: "Vital and Alive - an Exploration of Subjective Vitality and Its Physiological Correlates" selbstständig verfasst, nur die angegebenen Quellen und Hilfsmittel benutzt und wörtlich oder inhaltlich übernommene Stellen als solche gekennzeichnet habe. Ich erkläre, dass die Richtlinien zur Sicherung guter wissenschaftlicher Praxis der Universität Tübingen (Beschluss des Senates vom 25.5.2000) beachtet wurden. Ich versichere an Eides statt, dass diese Angaben wahr sind und dass ich nichts verschwiegen habe. Mit ist bekannt, dass die falsche Abgabe einer Versicherung an Eides statt mit Freiheitsstrafe bis zu drei Jahre oder mit Geldstrafe bestraft wird.

Ort, Datum Unterschrift

Appendix E

Formating and Rights of Use

The APA style in its 7th edition was used throughout this dissertation. The formatting of the published studies was adapted to this style and may differ from the published form. Also, the numbering of headings, footnotes, tables and figures has been altered to give a coherent sequence.

The work at hand comprises two published articles. According to the guidelines of the publishers – Springer Nature and Frontiers Media SA (http://www.nature.com and https://www.frontiersin.org) – the original texts and graphics can be used by the author for scholarly, non-commercial purposes as it is the case with this dissertation.

Appendix F

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