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UNIVERSITY OF SKÖVDE

FINDING WELL-BEING BETWEEN HEARTBEATS: AN EMPIRICAL STUDY CORRELATING SUBJECTIVE WELL-BEING WITH HIGH FREQUENCY HEART RATE VARIABILITY

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Nathalie Helle

Examiner: Andreas Kalckert

Abstract

Physical health can be measured in several ways both based on subjective experiences and with objective tools. However, mental health can only be measured through subjective experiences and sensations, which can be biased. Therefore, researchers adopted the notion of an objective tool to assess well-being as a complement to existing self-reported scales and suggested that heart rate variability (HRV) might be an indicator of well-being. Hence, this thesis investigates the relationship between subjective well-being (SWB) and HRV, particularly high frequency-HRV (HF-HRV). Three hypotheses, which included different forms of well-being, were developed to test the relationship. And the hypotheses were: Cognitive well-being correlates positively with HF-HRV. Positive affect correlates positively with HF-HRV, and negative affect correlates negatively with HF-HRV. A total of 19 healthy Swedish females aged from 20-35 participated and answered questionnaires measuring SWB. After they completed the SWB-scales, their heart rate was measured and then converted into HF-HRV data. The findings revealed no correlations between the cognitive SWB and HF-HRV, neither to affective SWB.

Keywords: subjective well-being, heart rate variability, high-frequency heart rate variability, correlational study, cognitive neuroscience.

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Introduction

Two essential characteristics of a good life are health and happiness (Diener & Chan, 2011). In today's modern society, doctors assess physical health from different facets. They ask the patient how they feel and use instruments to assess health objectively. Doctors can, for instance, measure heart rate and blood pressure, and they could also detect if we suffer from any disease via blood tests. Science has come a long way to assess physical health, but what about mental health?

Several self-report tests (e.g., PANAS; Watson et al., 1988) are available to assess mental health. However, there is no scientifically accepted measurement that objectively assesses well-being, although such a tool might be needed. Researchers (e.g., Diener, 2000) claim that different biases can influence self-report tests because they are calculated from subjective sensations and opinions. For example, it is easy to answer in a socially accepted way instead of expressing how one truly feels or be influenced by interfering surroundings or moods.

Consequently, biases might affect the respondent's answer and result in incorrect prediction of one's well-being (Diener, 2000). To solve this problem, an objective tool to assess mental health could avoid such biases and measure well-being from additional perspectives. Furthermore, measuring the time variation between heartbeats might be a potential objective marker of well-being (Kemp & Quintana, 2013).

Yet, what is well-being? Individual well-being has been ignored by researchers for decades, instead, the focus has been on unhappiness. It was not until 1973 happiness became an index term (Diener, 1984). Furthermore, well-being is a mixture of experienced thoughts and emotions, and Diener (2000) describes that self-perceived thoughts and emotions about life, are defined as subjective well-being (SWB).

Furthermore, thoughts and emotions are not only coupled with well-being. Researchers claim that thoughts and emotions are also linked to activity in the nervous system (Critchley et al., 2013). The nervous system receives and conveys signals from and to different parts of the body, and one task is to regulate heartbeats (Gazzaniga et al., 2013). Researchers have found that the time variation between heartbeats, named heart rate variability (HRV), is linked to the autonomic nervous systems activity (Billman, 2011). An optimal HRV is positively associated with well-being (Shaffer et al., 2014). On the other hand, a reduced HRV relates to mental and physical disorders, e.g., depression and cardiovascular diseases (Kemp & Quintana, 2013).

Assessing SWB with HRV is a new research field, and there are few studies. A search on PubMed for "Subjective well-being + Heart rate variability" on April 16th, 2020, generated only 330 articles (for comparison, a search only on "subjective well-being" generated 54,766 articles, and "heart rate variability" generated 25,944 articles). More research is needed to better understand the relationship between SWB and HRV. Therefore, this thesis intends to investigate the relationship between SWB and HRV by correlating SWB with high frequency- HRV (HF-HRV), which is a measure of the parasympathetic nervous system activity (Shaffer et al., 2014).

Moreover, the thesis begins by describing the concepts of SWB and HRV to get a clear picture of the meanings of the concepts and underlying causes. Afterward, previous research within the field is described. Then, the method and results for this thesis are presented, and the thesis ends up with discussing the results, limitations, and thoughts for future research. The hypotheses for this correlational study are based on results from previous investigations and relevant theories. The hypotheses are; cognitive well-being correlates positively with HF-HRV. Positive affect correlates positively with HF-HRV and negative affect correlates negatively with HF-HRV. SWB will be measured based on reliable self-reported scales, and then correlated to HRV. However, the results revealed no significant correlation between either cognitive SWB or affective SWB. Due to conflicting results from this current study and earlier studies, there is reason to be skeptical whether HRV is a reliable objective measure for SWB.

Subjective Well-Being

Well-being is a concept with different meanings and theories. Psychological researchers often divide well-being into either the hedonic or the eudaimonic tradition (Deci & Ryan, 2008). The hedonic tradition highlights and defines well-being as individual interpretations of pleasure and displeasure from both bodily and psychological sensations. On the other hand, the eudaimonic tradition embraces the fulfillment of human potential and how to achieve that fulfillment (Ryan & Deci, 2001).

The hedonic approach is, compared to the eudaimonic, a further defined and distinct concept with developed measurements and a general agreement between researchers (Kashdan et al., 2008). Furthermore, SWB is often found within the hedonic tradition (Deci & Ryan, 2008). SWB is described, as "people's cognitive and affective evaluations of their lives" (p. 34), according to Diener (2000). Even though SWB is said to be included in the hedonic tradition, a cognitive perspective generally is not (Deci & Ryan, 2008). Therefore, it would be relevant to discuss whether SWB should be referred to as pure hedonic well-being, but that should be carried out in another essay.

As mentioned, the concept of SWB includes a cognitive evaluation of life, referring to and how satisfied one thinks one is with life. The cognitive component involves satisfaction with specific life domains (domain satisfaction), e.g., satisfaction with health, self-esteem, work, and relationships (Diener et al., 1999). It also includes cognitive satisfaction about both a person´s past, present, and future life. Cognitive well-being can be seen as a personal and global evaluation of life (Tov & Diener, 2013).

However, unlike cognitive well-being that includes thoughts about life, the affective component of SWB evaluates emotional experiences (moods and emotions). Furthermore, affective well-being is divided into positive and negative affect. Positive affect has a higher value than its negative counterpart, for example, vigorous-intensity (more frequent feelings of joy, contentment, pride-, or happiness) are preferred over feelings of sadness, anxiety, anger, depression, guilt-, or shame (Diener et al., 1999). The cognitive and affective components of SWB are distinct but interrelated constructs (Diener, 1984), and they are most often assessed via self-reported questionnaires (Diener et al., 1999). Concluding, the concept of SWB focuses on the fact that well-being is a subjective experience, with high levels of life satisfaction, domain satisfaction, positive emotions, and lower levels of negative emotions.

Subjective Well-Being and Health

This section provides a brief overview of the correlation between SWB and health (with a primary focus on cardiovascular health) since researchers presume there is a relationship between happy people and better health (De Neve et al., 2013; Diener & Chan, 2011). Studies have revealed a significant mean correlation (r=.32) between happy people and self-reported good health (Pressman & Cohen, 2005).

Furthermore, cognitive well-being correlates with physical exercise, healthy eating, and non-smoking habits (Grant et al., 2009), and people with a greater level of life satisfaction are also less likely to commit suicide or become depressed (Diener et al., 1999). Cognitive skills (also called executive functions), such as flexible thinking and self-control (Diamond, 2013), have been shown to relate to cardiovascular functions, for example, the pulse rate and the ability to inhibit unsuitable responses (Thayer et al., 2009). On the other hand, cognitive impairment correlates to heart failure (Vogels et al., 2007)

Moreover, positive affect is also associated with several health benefits. For example, higher trait positive affect (one's typical emotional experiences) correlates with lower morbidity, pain, and lower mortality rates. It also relates to behavioral, social, and physiological mechanisms, reducing morbidity and mortality (Pressman & Cohen, 2005). Furthermore, state positive affect (temporary responses) is also associated with both increased and decreased cardiovascular systems. Researchers believe that emotions like joy and excitement (highly activated emotions) increase the heart rate and blood pressure, whereas feelings of calm and content (lower activated emotions) do not increase, or increased very little, cardiovascular activity (Pressman & Cohen, 2005).

The fact that positive emotions influence cardiovascular activity is additionally supported by Fredrickson and Levenson (1998) and their undoing hypothesis. The hypothesis describes how positive emotions stimulate the cardiovascular system and change the activity after negative emotions have influenced our cardiovascular system by increasing its activity (Fredrickson & Levenson, 1998).

Positive emotions are accordingly associated with health and recovery; however, negative emotions, on the other hand, are associated with ill-health. Negative emotions such as depression (Glassman & Shapiro, 1998), anxiety, and chronic psychological stress (Cohen et al., 2015) relate to cardiovascular disorders. Consequently, SWB is associated with health, and the mind and body seem to be connected. We respond to the state of the body and can also change its state due to affect and cognition (Critchley et al., 2013). Even if the relation between SWB and health outcomes seems quite robust, various factors can influence SWB (and, possibly by extension, also health). Therefore, the next section describes different factors influencing SWB.

Factors Influencing Subjective Well-Being

SWB can be influenced by both psychological and demographic factors. One of the most consistent predictors is personality style (Diener et al., 1999). It is assumed that people have a genetic predisposition to be happy or unhappy and that extroverts generally live through more positive feelings than introverts. Furthermore, self-esteem and optimism are likewise strongly related to SWB, particularly the cognitive component (Diener et al., 1999).

Another factor assumed to influence SWB is age. Data from an international study found no changes between cognitive SWB and age within a lifespan. However, affective SWB declines with age, including both positive- and negative affect. Moreover, negative affect only declined up to the age of 60. When passing 60 years of age, negative affect appears not to further decrease (Lucas & Gohm, 2000).

In addition to personalities and age, culture is a third factor that influences our SWB (Diener et al., 2017). For example, in Pacific Rim cultures, positive emotions with a low level of arousal (e.g., contentment) have a higher value. In contrast, positive emotions with higher arousal levels (e.g., excitement) are valued more in western cultures. Moreover, life satisfaction seems to differ slightly across cultures (Diener et al., 2017).

Furthermore, it has been concluded that SWB can be increased by specific interventions which either increase positive emotions and life satisfaction or decrease negative emotions. For example, expressing gratitude increases positive emotions (Lyubomirsky & Layous, 2013). On the other hand, physical exercise reduces negative emotions (Ströhle, 2009). Life satisfaction could be increased by detecting unfulfilled areas in one's life (life domains); for instance, increased self-esteem enhances life satisfaction (Diener & Diener, 2009). SWB can also increase when engaging in self-regulating activities-, where regulating our emotions is just one example (Quoidbach et al., 2010). Emotion regulation is a crucial factor in promoting well-being (Sakaki et al., 2016). It refers to how we influence and regulate our expressed and experienced emotions (Gross, 1998).

To summarize, when we are cognitively satisfied with life, and when positive affect outweighs negative affect, we experience SWB. SWB is beneficial for both our physiological and psychological well-being. Personalities and other factors influence SWB, and it is possible to enhance our SWB with interventions. The next section discusses how to measure SWB.

Measuring Subjective Well-Being

Both cognitive and affective components are measured when assessing SWB, to capture a whole dimension of well-being (Diener et al., 1999). Self-report questionnaires require the respondent to evaluate his or her cognitive and affective well-being subjectively. Several self-report questionnaires assess SWB, and according to Diener (2000), different tests have different qualifications and limitations.

Two of the most cited are the Satisfaction With Life Scale (SWLS; Diener et al., 1985) and the Positive Affect and Negative Affect Schedule (PANAS; Watson et al., 1988) (Tov & Diener, 2013). SWLS measures cognitive well-being, and cognitive fulfillment according to our wishes, expectations-, or needs in life (it does not measure domain satisfaction). Furthermore, the Temporal Satisfaction with Life Scale (TSWLS; Pavot et al., 1998) is a developed form of SWLS and further includes dimensions of past, present, and future satisfaction with life.

PANAS, on the other hand, measures our affective well-being; positive and negative affect. These two aspects are inversely correlated, although separable (Watson et al., 1988). The test shows high test-retest reliability, convergent validity, and internal consistency (Thompson, 2007).

Furthermore, numerous other scales are used for measuring different aspects of SWB, although only the two measures of interest will now be described. The Brunnsviken Brief Quality of Life Scale (BBQ: Linder et al., 2016) measures the cognitive aspect of SWB. The test is used to identify areas of life (domains) with the greatest impact on self-perceived quality of life. The second test is UWIST Mood Adjective Check List (UMACL: Matthews et al., 1990). It measures the affective component of SWB, particularly our present mood, which is further divided into various subscales. Those subscales include hedonic tone, which measures the overall pleasantness of our mood (cheerful vs. dissatisfied), tense arousal, which measures feelings of subjective tension (calm vs. anxious), and energetic arousal, which measures feelings of subjective activation moods (active vs. passive). Moreover, the method chapter will describe all the measures mentioned in further detail.

As mentioned in the introduction, despite reliable and validated tests, there is a risk of measurement bias when using self-assessed questionnaires. Situational factors, such as disturbing surroundings and our current mood-, might influence at respondent's answer. Additionally, participants might tend to answer in a socially accepted way (social desirability bias) instead of how they truly feel (Diener, 2000). Furthermore, the response-shift bias could occur from pre-tests and post-tests, meaning that the respondent's answers might be misleading if their knowledge has changed between the first time the test was performed and the second time (Rosenman et al., 2011).

Since subjective responses could be biased, it would be appropriate to embrace an objective measure of SWB, a statement supported by well-being researchers (e.g., Diener, 2000). Assessing SWB with both self-reported- tests and objective tests expands the picture of our well-being. One objective way to quantitatively assess SWB could be by using HRV as a marker for SWB (Kemp & Quintana, 2013; Shaffer et al., 2014). Moreover, it requires knowledge about HRV to understand why it is of interest to use it as a marker for well-being.

The next chapter briefly describes HRV, how the brain and heart are interconnected, how to measure HRV and the factors that can affect HRV.

Heart Rate Variability

The nervous system consists of the brain, spinal cord, and nerves in the body. The nervous system is divided into the central- and peripheral nervous system. The brain and spinal cord create the central nervous system, whereas nerves that lead through the body forms the peripheral nervous system (Gazzaniga et al., 2013). The central nervous system sends and receives signals from the brain via nerves. Moreover, the peripheral nervous system delivers those signals to our muscles and glands and sends them back to the central nervous system from muscles and glands (Gazzaniga et al., 2013). The peripheral system is also further divided into the autonomic nervous system, and the somatic nervous system (Gazzaniga et al., 2013). The autonomic nervous system is the focus of this thesis and will be further described below.

We cannot intentionally control the autonomic nervous system. The system controls internal organs, for example, the rhythm of the heart. The autonomic nervous system contains two branches, the parasympathetic- and sympathetic branches (Gazzaniga et al., 2013). The parasympathetic nervous system is predominant at rest. It releases the neurotransmitter acetylcholine, which makes the heartbeat slower (Kemp & Quintana, 2013). Activity from the parasympathetic nervous system is also referred to as vagal tone because the central nerve of the parasympathetic nervous system is named the vagus nerve (Laborde et al., 2017).

Furthermore, the sympathetic nervous system is known as the ‘fight or flight’ system, making the heart pump faster by releasing the hormone norepinephrine (Kemp & Quintana, 2013). An activated sympathetic nervous system generates a higher heart rate. The sympathetic nervous system is stimulated, for example, during physical exercise, in stressful situations, or if someone is suffering from heart disease (Acharya et al., 2006).

When the body is resting, the two branches maintain a dynamic balance, although the activity of the parasympathetic nervous system dominates. Furthermore, an imbalance between the two systems could lead to pathologies. An imbalance often appears if the sympathetic nervous system is abnormally active, and the parasympathetic system is underactive (Thayer & Lane, 2009).

Electrocardiography (ECG) is a method used to illustrate the activity of the heart, this enabled the heart's activity to be measured for both shorter and longer periods (Billman, 2011). The activity of the heart can then be seen on a diagram revealing waves, with peaks and troughs. Three of those waves are labeled; Q, R, and S (see figure 1). Together they reflect the depolarization of the heart's ventricle (Billman, 2011). For this thesis and context, the time between two R-waves (the R-R interval) is of interest because HRV is defined as the time variation between these (Acharya et al., 2006). Furthermore, heart rate refers to the number of heart beats per minute, and HRV measures the variation in time between each heartbeat (Acharya et al., 2006).

HRV is used as a marker for diseases and is an index of cardiovascular and nervous system activation (Acharya et al., 2006). A higher time variation is preferred as opposed to a lower time variation. Although, it is necessary to know that some pathological states might also generate a higher HRV (Shaffer & Ginsberg, 2017). However, an optimal level is beneficial and appears to be related to flexibility and adaptability, which characterizes healthy functioning and well-being (Shaffer et al., 2014).

The next section focuses on HRV and its connection to the brain, describing the neurovisceral integration model, a model created through neuroscience research (Ernst, 2017).

Figure 1. This figure demonstrates the characteristics of HRV. An ECG graph show a series of QRS complexes. It shows the time variation (in milliseconds) between four R-R intervals.

Firstbeat. (n.d). An ECG graph showing a series of QRS complexes. Retrieved on May 26th, 2020, from https://www.firstbeat.com/sv/blog-sv/vad-ar-pulsvariabilitet-och-varfor-ar-den-viktig/

Heart Rate Variability and Brain Connection

The neural communication between the heart and the brain is a complex phenomenon. A cardiovascular center located in the medulla (a part of the brainstem) is responsible for adjusting parasympathetic and sympathetic activation. This cardiovascular center receives information from both the heart, the cerebral cortex (outer brain layer), and the limbic system (a set of structures in control of emotions, memories, and arousal) to adjust the autonomic nervous system (Shaffer & Venner, 2013).

Furthermore, HRV reveals activity from the autonomic nervous system, which in turn, is assumed to reflect the state of the brain. (Thayer et al., 2012). Several individual neuroimaging studies found a relationship between HRV and specific brain regions. Thayer et al. (2012) collected these studies to a meta-analysis and found three brain regions linked to HRV. One of the areas linked to HRV was found in the amygdala, which is a region that mediates emotional reactions. For example, the amygdala mediates adaptive "fear" responses and identifies potential threats. The remaining two areas were found in the medial prefrontal cortex, one in the right pregenual cingulate and the other area in the right subgenual cingulate (Thayer et al., 2012).

The prefrontal cortex is located in the brain's frontal lobe and is responsible for planning, organizing, and executive functions (Gazzaniga et al., 2013). Executive functions are essential for mental and physical health, and the core executive function is to know how to regulate one's attention, behavior, thoughts, and emotions (Diamond, 2013). When engaging in emotion regulation, the medial prefrontal cortex (and the anterior cingulate cortex) changes the amygdala's activation (Etkin et al., 2011), and individuals better at regulating emotions seem to have greater HRV (Appelhans & Luecken, 2006). Furthermore, the connection between the prefrontal cortex and HRV is explained by the neurovisceral integration model below.

Neurovisceral Integration Model. The neurovisceral integration model perceives HRV as an output from the central autonomic network (Thayer & Lane, 2009). The central autonomic network includes specific neural structures (involved in cognitive, affective, and autonomic regulation) that regulate the heart rate and HRV (Thayer & Lane, 2000). In summary, HRV is controlled via the autonomic nervous system, and this system is regulated by brain areas known as the central autonomic network, which connects parasympathetic and sympathetic neurons to induce the heart (Thayer & Lane, 2000).

Functionally the central autonomic network includes an internal regulation system where the brain controls responses that are important for elements, such as, adaptability and health (Thayer & Lane, 2009). The Neurovisceral integration model suggests that higher activation from the parasympathetic nervous system leads to better cognitive and emotional functioning and health regulation (Thayer, 2009).

However, the network is complex and further structured into four hierarchical areas, linking forebrain areas and the brainstem with bidirectional communication (Thayer &

Friedman, 2004). Moreover, the prefrontal cortex, limbic structures, and the brain stem are the areas that form the central autonomic network (Ernst, 2017), and the prefrontal cortex can be illustrated as a conductor. The prefrontal cortex has inhibitory control over other brain regions, such as the amygdala, brainstem nuclei, and hypothalamus (Thayer & Lane, 2009). Inhibition from the prefrontal cortex is needed, for example, when adjusting or regulating emotions. If the conductor stops conducting, for whatever reason, a sympathetic signal releases and automatic processes start, and the subcortical regions take over. Less active prefrontal cortex can be useful when we need to react fast for survival (often referred to as 'fight or flight') (Thayer & Friedman, 2004).

Consequently, the neurovisceral integration model explains the heart-brain connection by embracing hierarchical steering, where the prefrontal cortex is the conductor for monitoring heart rate and HRV. The following section describes how HRV is measured (in particular the measurements used for this thesis), and factors that might influence HRV.

Measuring Heart Rate Variability

Collecting HRV data is pain-free and quick to perform, it is done by measuring the heart rate via an ECG (Kleiger et al., 2005). Measures of HRV have shown stability over a 3- to 65-day interval with no placebo effect (Stein et al., 1994). HRV is assessed through either frequency domain, time domain, or non-linear measurement analysis (Billman, 2011). Furthermore, heart rate can be collected for a shorter (5min) or a more extended (24 hour) period. It is important to understand that short-term measurement should only be compared with other short-term measurements, the same applies to long-term measurements. The current experiment investigates the frequency-domain analysis and short-term measurement, which is further described below.

Frequency-domain analysis and short-term measure. Electrical activity from both the parasympathetic nervous system and the sympathetic nervous system regulates heart rate (Acharya et al., 2006). An ECG measures heart rate and collects HRV data, and the frequency-domain analysis analyzes the HRV data by dividing the recorded electrical activity into four different frequency bands (Shaffer & Ginsberg, 2017). When using the frequency-domain method, we are interested in the underlying physiological mechanisms that influence our heart rate (Stein et al., 1994). Moreover, the four different frequency bands are: The high frequency (HF) band which are detectable between 0.15 and 0.40 Hz, the low frequency (LF) band, which is detectable between 0.04 and 0.15 Hz, the very-low frequency band (0.003-0.04 Hz), and the ultra-low frequency band (≤.003 Hz) (Malik et al., 1996).

Furthermore, the frequency-domain measurements quantify HRV by calculating the data into absolute or relative power. Absolute power is used for this current experiment and calculates as ms squared divided by cycles per second (ms2/Hz) (Shaffer & Ginsberg, 2017). It is also the most used unit when analyzing HF-HRV through frequency domain analysis (Malik et al., 1996). Moreover, the current experiment focuses on the HF-band, and it is, therefore, further described. The HF-band is assumed to represent the activity from the parasympathetic nervous system (Stein et al., 1994). The HF-band is supposed to assess health and adaptability (Winkelmann et al., 2017). Moreover, stress (Taelman et al., 2009), panic, worry (Shaffer & Ginsberg, 2017), and anxiety disorders (Chalmers et al., 2014) correlate with a low HF-HRV value. Furthermore, dividing HRV into the high-frequency (HF) band can be done by two different techniques, the fast Fourier transform analysis technique or the autoregressive modeling. The two methods have various advantages and disadvantages, though they are assumed to yield equal results (Berntson et al., 1997).

When measuring HF-HRV, it is crucial to breathe normally (~11–20 bpm) since breathing might affect HRV (Shaffer & Ginsberg, 2017). Furthermore, is the term respiratory sinus arrhythmia (RSA) used when inhalation and exhalation change the heartbeat (Shaffer &

Venner, 2013). RSA is often used interchangeably with HRV, although they are two different concepts (Billman, 2011).

Factors Influencing Heart Rate Variability

One initial factor influencing HRV is breathing. Inhaling and exhaling change our heart rate. While inhaling increases the heart rate, exhaling causes it to decrease (Shaffer & Venner, 2013). Moreover, gender is a dependent variable. Whether someone is female or male, seems to be a factor that plays a role when measuring HRV. A meta-analysis shows that HRV differs between genders, females exhibit a lower total power across all frequency domains compared to males; however, they exhibit higher power in the HF band (Koenig & Thayer, 2016). Another factor is age. HRV seems to decrease with age within healthy participants (Antelmi et al., 2004). However, this does seem to differ depending on the analysis method used (Umetani et al., 1998).

Further factors that influence HRV are diseases, smoking, and alcohol consumption. Coronary heart disease is associated with lower HRV (Dekker et al., 2000), and individuals who suffer from myocardial infarction have a decreased HRV. Likewise, individuals with either diabetes (Acharya et al., 2006) or depression reveal a relationship with a lower HRV (Kemp et al., 2010). However, taking antidepressant medication (except tricyclic medication) seems not to affect HRV (Kemp et al., 2010). Additionally, smokers have diminished activity from the parasympathetic nervous system (Hayano et al., 1990), and HRV is decreased in heavy smokers when compared to nonsmokers (Barutcu et al., 2005). Alcohol also seems to have a decreasing effect on HRV (Acharya et al., 2006; Koskinen et al., 1994). On the other hand, caffeine seems to increase HF-HRV (Koenig et al., 2013).

Also, athletes reveal a higher HRV (Verlinde et al., 2001). Moreover, different stages of sleep demonstrate varying levels of HRV (Acharya et al., 2006). There are also studies indicating that obesity changes HRV. Individuals highly overweight have higher sympathetic activation, whereas parasympathetic activation is suppressed (Karason et al., 1999). Furthermore, when measuring HRV, it is crucial to standardize posture. Standing up or having the head tilted upwards is assumed to cause a significant decrease in HF power (Kleiger et al., 2005).

To conclude, HRV is presumed to be an indicator of the autonomic nervous system's activity. A higher HRV relates to a balanced autonomic nervous system, health, and adaptability. It is possible to assess parasympathetic activity alone by analyzing the higher frequency domain, however, different variables could influence HRV.

The next chapter presents correlational studies that have correlated components of SWB with HF-HRV.

Examining SWB and HRV Together

Some studies have suggested a correlation between SWB and HRV, in particular, between the affective component and HF-HRV (e.g., Geisler et al., 2010; Sloan et al., 2017). This chapter aims to provide the reader with previous research that has correlated SWB with HF-HRV. The presented studies used short-time and frequency domain analysis and assessed HRV in a resting state. However, two of the scientific articles (Oveis et al., 2009; Wang et al., 2013) reported that they measured RSA, and to remind the reader, RSA is when inhaling increases the heart rate while exhaling decreases it. Furthermore, Oveis et al. (2009) followed the standards of measurement for high-frequency heart rate variability when they assessed RSA and Wang et al. (2013) used the high frequency of heart rate variability to assess RSA. Below, the studies are introduced in chronological order.

To begin, Oveis et al. (2009) tested the relationship between RSA and the individual positive affect and negative affect (at tonic level) within 80 students (males and females) with a mean age of 20 years. They used PANAS to assess enduring positive and negative moods and found a positive correlation between a positive mood and RSA.

Interestingly, they also correlated RSA with personality traits related to positive and negative emotions and found a positive relationship between being an extrovert (a factor influencing SWB) and RSA (Diener et al., 1999).

Geisler et al. (2010) correlated HF-HRV with TSWLS (assessing cognitive SWB) and UMACL (assessing affective SWB). This study had a sample size of 172 participants, including both males and females, with a mean age of 23 years old. They found no correlations between TSWLS and HF-HRV. However, they found a significant positive correlation between higher hedonic tone (the ability to feel pleasure) and HF-HRV. Likewise, they found a significant positive correlation between higher tense arousal (feelings of calmness) and HF-HRV.

Furthermore, Krygier et al. (2013) examined both cognitive and affective SWB, using SWLS and PANAS in relation to HF-HRV. The study included a sample size of 37 participants, both men, and women, with a mean age of 43.8 years. They found a negative relationship between negative affect and HF-HRV. However, they did not find any significant correlation between the cognitive component of SWB and HF-HRV.

A fourth study by Wang et al. (2013) correlated PANAS, and a test assessing emotional expressivity, with RSA (estimated by HF-HRV). 77 participants were involved, including both males and females, with a mean age of 20 years. After 4 and 12 months, the participants conducted the tests again, and the researchers found on all occasions that RSA correlated with positive trait affect (inherent qualities to experience positive feelings).

The most recent study (Sloan et al., 2017) included 967 participants, both males, and females, with a mean age of 54 years. They assessed hedonic well-being using both PANAS and one self-administrated test and correlated those with HF-HRV. After adjusting for covariates (age, sex, BMI, menstrual status, site, medications affecting parasympathetic activity negatively or positively, smoking, heart disease, Parkinson's or any other neurological condition, a history of stroke, and further correlated for respiration rate), they discovered a significant negative relationship between negative affect and HF-HRV.

Hence, studies, described above, have correlated HF-HRV with measurements measuring either cognitive or affective SWB, and have found significant positive and negative correlations between HF-HRV and positive or negative affect.

Furthermore, a review regarding activity from the autonomic nervous system relating to different types of emotions describes how positive feelings both increase and decrease HRV. Feelings of joy and amusement correlate with increased time variation between heartbeats. On the other hand, happiness correlates with reduced time variation (Kreibig, 2010). Researchers have also found correlations between negative emotions and decreased HRV (e.g., Kemp et al., 2012; Kemp et al., 2010; Licht et al., 2008).

Even though none of the studies mentioned above revealed a correlation between cognitive SWB and HF-HRV, other researchers suggested that executive functions do change HRV. Higher executive functions correlate positively with HRV, and impaired cognitive control seems to decrease HRV (Thayer et al., 2009).

Moreover, based on previous specific studies that correlated components from SWB with HF-HRV and other articles that examined the relationship between the autonomic nervous system, emotions, and cognition, this thesis aims to expand the number of investigations correlating SWB with HRV. The general hypothesis is that SWB correlates positively with HF-HRV. To investigate this, the general hypothesis was separated into three hypotheses for this study: Cognitive well-being correlates positively with HF-HRV, positive affect correlates positively with HF-HRV, and negative affect correlates negatively with HF-HRV. The next chapter describes the method for the empirical part of this thesis.

Method

Participants

19 females participated in this study, ranging from 21-32 years (*M*-age=24.88, SD= 3.08). 18 of the participants were students from the University of Skövde. The study included only females to get a more homogenous sample since there are potential differences in HF-HRV between genders. Females have shown higher power in the HF band (Koenig & Thayer, 2016). Besides excluding men, only females aged between 20-35 years were allowed to participate since HRV also relates to age differences (Antelmi et al., 2004). Another criterion for participation was that the participants had to consider themselves as healthy. They were not allowed to consume any medication for heart or psychiatric illness or use drugs. The participants were asked not to drink caffeine at least two hours before the experiment, and not to use nicotine or alcohol for the last five hours before the procedure (Acharya et al., 2006). Information about the study was disseminated via email, notes on the bulletin boards at the University of Skövde, and personal communication. Participation was voluntary.

Procedure

The participant first signed informed consent and gained information about their participation. After this, they received a battery of questionnaires assessing components of SWB. However, they could call the researcher if they had any questions. The instructions were to read the questions carefully and answer them honestly and truthfully, taking the time they needed. The questionnaire was delivered in the following order: UMACL, TSWLS, BBQ, and PANAS.

The UMACL was translated from English to Swedish by the author of the thesis. Furthermore, the translation was discussed with others who had a good understanding of English to get the most accurate and consistent translation. The TSWL and PANAS had already been translated into Swedish by the University of Skövde. The BBQ is originally a Swedish scale, and was, therefore, not translated.

The next part involved the ECG and HRV measurements. The participants received instructions and were given an image (see Figure 2) showing them how to wear the ECG.

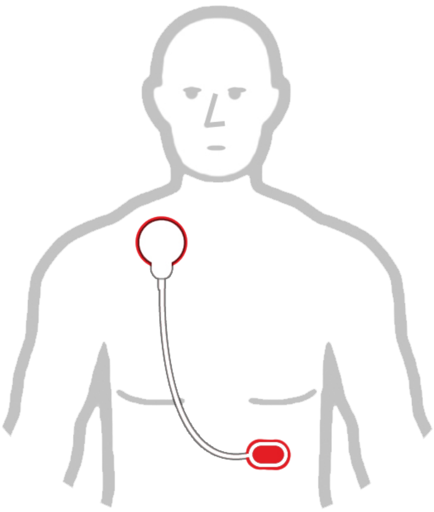

Figure 2. This picture shows how the ECG device should be attached.

Firstbeat. (n.d). How ECG advice should be attached. Retrieved May 26th 2020, from https://support.firstbeat.com/hc/en-us/articles/360015724014-Attaching-the-Bodyguard-2-and-electrodes.

The participant put the ECG monitor on by themselves. However, the researcher checked the device before measurements took place, so the ECG was correctly placed and connected. The participant was then told to sit still for approximately 12 min with their both feet on the ground in a relaxed and upright position without doing anything that could distract them (Berntson et al., 1997). The researcher left the room and returned after 15 minutes, told the participant to take off the ECG device, and then the study was complete. The participants took part in the procedure during the daytime between 8:00 am and 5:00 pm.

Measurements

Mood Adjective Check List (UMACL). UMACL (Matthews et al., 1990) is a checklist containing 29 adjectives describing moods and feelings. The test reflects different moods felt in the present moment. The participants rated their experience on a 4-point Likert scale, where 1 indicated ‘definitely not’, and 4 indicated ‘definitely’. The UMACL consists of three subscales (hedonic tone, tense arousal, energetic arousal) and has 8 adjectives for each subscale. Hedonic tone measures the overall pleasantness of mood (cheerful vs. dissatisfied), tense arousal measures feelings of subjective tension (calm vs. anxious), and energetic arousal measures feelings of subjective activation moods (active vs. passive). Scores range from 8 to 32 for each subscale, a higher score indicating either a higher hedonic tone, tense arousal, or energetic arousal.

The temporal Satisfaction with Life Scale (TSWLS). TSWLS (Pavot et al., 1998) measures cognitive satisfaction with life within three subscales concerning satisfaction with past, present, and future life. It contains 15 statements, 5 for each subscale-, rated on a Likert scale of-, 1 to 7, where 1 indicates ‘strongly disagrees’, and 7 indicates ‘strongly agree’. The score can range from 5-35 for each subscale.

The Brunnsviken Brief Quality of Life Scale (BBQ). BBQ (Linder et al., 2016) measures the quality of life. The test consists of 12 questions rated on a Likert scale from 1-4, where 1 indicates do not agree, and 4 indicates total agreement. The scores range from 0-96

The Positive Affect Negative Affect Schedule (PANAS). PANAS (Watson et al., 1988) measures dispositional affect, the overall tendency to respond positively or negatively to an event. PANAS is considered a reliable measurement when assessing trait affect due to its long-term stability (Watson & Walker, 1996). PANAS consists of 10 items reflecting positive affect and 10 items reflecting negative affect. The items are rated on a Likert scale from 1-5, where 1 indicates 'very slightly' and 5 'extremely'. The participants rated the 20 items according to how they felt in general. The scores range from 10-50, for both positive and negative affect.

Heart Rate Variability. The participant's heart rate was measured sitting in a resting state for 15 min using the Firstbeat Bodyguard 2 device (ECG). The manufacturer developed Firstbeat Bodyguard 2 to evaluate athletes' performance and recovery, however, it is also used to assess well-being and various health factors even for non-athletes (Firstbeat, 2021). Furthermore, the device has a correct detection of 99.95% of all heartbeats without artifact correction and 99.98% with artifact correction, compared to standard clinical ECG (with off-line R-wave detection). The device has been tested in both resting state and during activities and is accepted as an accurate device for monitoring HRV in healthy subjects (Parak & Korhonen, 2013).

Moreover, two ECG electrodes were located on the upper body, one underneath the clavicle on the right side, and the other on the bottom rib on the left side (see Figure 1). HRV was measured for a shorter period and then assessed with the frequency-domain analysis. This method generally performs with a short-term (5min) measure (Kleiger et al., 2005). Moreover, the heart rate was measured for a total of 15 minutes, 10 of those minutes were divided into two five-minute periods, which was calculated to one mean HF-HRV value. The three first minutes were not analyzed; however, they were added so that the participant had time to feel comfortable with the device, the environment, and get in a comfortable position. The last two minutes were added to ensure that 10 minutes would be measured but were later removed considering only two five minutes segment were needed. Five-minute segment is standard for shorter measurements when measuring HF-HRV in the frequency domain analysis (Kleiger et al., 2005).

The Firstbeat Analysis Server analyzed the HRV and divided it into the high-frequency band (0.15-0.4Hz). HF-HRV was measured in ms^2, which is, as mentioned before, most commonly used when measuring HF-HRV via the frequency domain analysis (Malik et al., 1996).

Analyzing the Data

The Firstbeat Bodyguard 2 device recorded the participant's heart rate. The instrument detected the R-peaks from the ECG signal, and then, the HRV was then calculated using frequency measures and the short-time Fourier transform method, measured in ms^2. The Firstbeat Analysis Server software (version 7.5) was used to analyze the data. Firstbeat's analysis program performed the calculation and the analysis (see Appendix for the calculation- and analysis method). IBM SPSS Statistics 25 was used for all statistical analyses. The bivariate analysis measured the strength of association between HF-HRV and SWB, using Spearman's *rho* correlation.

Result

Descriptive data are presented in Table 1.

Table 1. Descriptive statistics

Variable	Mean	SD	Min	Max
HF-HRV	3259 .44	2945 .04	56.97	10 836 .45
UMACL-HT	17 .74	2 .45	12	21
UMACL-TA	19 .26	1 .91	16	23
UMACL-EA	17 .74	2 .23	11	21
BBQ	67 .47	9 .77	54	84
TSWLS-PA	19 .42	6 .87	5	33
TSWLS-PR	26 .11	6 .11	12	35
TSWLS-FU	25 .89	5 .79	14	34
PA(NA)S	35 .79	5 .85	28	45
(PA)NAS	16 .95	5 .13	10	29

Note: *N*=19. UMACL-HT =hedonic tone, UMACAL-TA= tense arousal, UMACAL-EA=energetic arousal. TSWLS-PA=past, TSWLS-PR=present, TSWLS-FU=future

Inspection of the descriptive statistics revealed that most measures fell within the expected ranges. Exceptions to this rule were HF-HRV, which had a surprisingly broader range than expected. However, HRV is individual and falls into individual preferences (*T.Myllymäki, Firstbeat, personal communication, April 10th, 2019*). Therefore, it was determined that the analysis could proceed as normal.

First boxplots from the descriptive statistics were visually inspected to gain a visual overview of the distribution of the data. According to a Shapiro-Wilk test ($p<.05$), HF-HRV was not normally distributed as well as UMACL-EA and BBQ. Additionally, the boxplot inspection revealed two outliers within the HF-HRV variable (with the HF-HRV value above 9000 ms^2). They were considered extreme values because they exceeded the 1,5 interquartile range. After this, the scatterplot tool in SPSS was used to check for linearity in all variables. However, the scatterplot did not reveal any linearity. Because of the non-linearity and some non-parametric variables, *Spearman's rho* was used to correlate the variables of SWB with HF-HRV. Due to 2 outliers, only 17 participants were included in the analysis. The correlations are presented in Table 2.

Table 2. Spearman's rho correlation between HF-HRV and SWB scales

-	1.
1.HF-HRV	
2.UMACL- HT	-.195 (.454)
3.UMACL- ET	.000 (1.00)
4. UMACL- EA	.089 (.735)
5.BBQ	.033 (.899)
6.TSWLS PA	.021 (.937)
7.TSWLS PR	.411 (.102)
8.TSWLS FU	.184 (.479)
9.PA(NA)	.158 (.545)
10.(PA)NA	.229 (.376)

Note: N=17. UMACL-HT =hedonic tone, UMACAL-TA= tense arousal, UMACAL-EA=energetic arousal. TSWLS-PA=past, TSWLS-PR=present, TSWLS-FU=future. Correlations between HF-HRV without outliers and SWB. The parentheses contain the calculated p-values. *Correlation is significant at the.05 level (2-tailed).

Discussion

The general aim of this thesis was to investigate the relationship between SWB (cognitive and affective well-being) and HRV. To do so, self-reported questionnaires assessing SWB were correlated to resting HF-HRV. The three hypotheses for the study were: Cognitive well-being correlates positively with HF-HRV, positive affect correlates positively with HF-HRV, and negative affect correlates negatively with HF-HRV. Though, no significant correlation was found between either cognitive or affective SWB and HF-HRV.

Furthermore, cognitive SWB was assessed with the TSWLS and BBQ questionnaire. There were no significant correlations between past, present, or future life satisfaction (assessed with TSWLS) or quality of life (assessed with BBQ). Moreover, PANAS and UMACL were used to measure affective SWB. However, no significant correlation was found between positive dispositional affect (assessed with PANAS) and HF-HRV or between negative affect (assessed with PANAS) and HF-HRV. There was also no correlation between hedonic tone, tense arousal, and energetic arousal (assessed with UMACL) and HF-HRV.

Even though this study did not reveal any significant correlations, other researchers have indicated some relationships between SWB and HRV, at least between the affective facet of SWB correlated to HF-HRV (Geisler et al., 2010; Krygier et al., 2013; Oveis et al., 2009; Sloan et al., 2017; Trimmel, 2015; Wang et al., 2013). On the other hand, there is no support for a relationship between cognitive SWB and HF-HRV. However, only two of the previous studies (Geisler et al., 2010; Krygier et al., 2013) and this thesis have studied the correlation between cognitive well-being and HF-HRV.

Furthermore, in the other studies mentioned above, there are correlations between SWB and HRV. However, it is important to pay attention to the different results that were found. Sloan et al. (2017) and Krygier et al. (2013) found a negative correlation between negative affect and HF-HRV, whereas Wang et al. (2013), Geisler et al. (2010), and Oveis et al. (2009) found a positive relationship between positive affect and HF-HVR. Even though relationships between affective SWB and HF-HRV have been found, it is still not clear exactly how HF-HRV could measure affective SWB.

Furthermore, why the results differ between studies might have to do with several reasons. For example, the design of each study varies-, likewise the sample size, the participant's gender and age, and the control for confounding variables in each study. The studies that revealed a positive relationship (Oveis et al., 2009; Wang et al., 2013) reported using RSA. However, RSA was assessed with HF-HRV. Furthermore, as mentioned before, RSA and HF-HRV are often used interchangeably. Though, they are two different phenomena (Billman, 2011). Another variable that may have affected the result is sample sizes. This present study analyzed 17 participants, while previous studies with significant results had at least 37 participants. The low number of participants could be another reason why there were no significant correlations in this study.

Furthermore, this study and Oveis et al., 2009 examined only females, whereas Geisler et al. (2010), Krygier et al. (2013), Sloan et al. (2017), and Wang et al. (2013) included both genders. However, studying both gender groups together could be misleading because males and females seem to differ in HRV, where females have revealed higher HF-HRV power compared to men (Koenig & Thayer, 2016). Moreover, age is another variable that might affect HRV (Antelmi et al., 2004). Most studies (Geisler et al., 2010; Oveis et al., 2009; Wang et al., 2013) had an equivalent mean age of 20-25. However, Krygier et al. (2013) and Sloan et al. (2017) had an average participant age of between 40 and 55 years.

On the other hand, the one similarity between all previous studies (Geisler et al., 2010; Krygier et al., 2013; Oveis et al., 2009; Sloan et al., 2017; Wang et al., 2013) and this study is that they all reported HRV from a resting state, and the sympathetic nervous system is therefore not intentionally activated.

Furthermore, when differences and similarities are discussed, is it noteworthy to discuss the extreme difference in the mean values of HF-HRV. This study had a mean value of 3259.44 ms^2, which is noticeably higher than other studies. For example, Geisler et al. (2010) had a mean value of 341.35 ms^2, and Sloan et al. (2017) revealed a mean value of 4.76 ms^2. However, since there were differences in how data was processed, this can explain the differences in those values. All studies (except this and Geisler et al., 2010) used the natural logarithm. Studies using log-transformed data had a mean HF-HRV between 4- and 7ms^2. In contrast, this research and Geisler et al. (2010) did not have log-transformed data and revealed higher mean values. Furthermore, Nunan et al. (2010) display normative HF-HRV data where mean HF-HRV is at 657 ms^2, based on 36 studies (M= 4.76 ms^2 for log-transformed data from 18 studies).

Nevertheless, this research still revealed a noticeably higher mean value compared to the normative data of Nunan et al. (2010). However, the higher value could, for example, depend on differences in age within the participants. The participants in Nunan et al. (2010) study were 40 years old or even older. The participants within this study were between 21 and 32 years old, and it is assumed that HRV decreases with age (Antelmi et al., 2004). Furthermore, the differences could also depend on sample sizes and the types of people who participated. Therefore, a larger sample size is to prefer since it might provide a wider variety of participants.

Concluding, at this present moment, it is not appropriate to compare and draw conclusions between the studies since there are too many factors that distinguish them. Instead, they should be seen as individual studies that can be used as supporting documents to further studies.

Limitations

There are limitations to this study, especially the limited number of participants. Moreover, essential factors that may affect HRV (e.g., caffeine intake, certain medications, illness) were not controlled for, except due to the restrictions for participating. Furthermore, the study did not control for participant's respiratory rates. Therefore, it is not entirely clear that the participants did not engage in self-regulation techniques, for instance, emotion regulation, a factor that could affect HRV (Appelhans & Luecken, 2006). However, this limitation is not unique to this study.

Another limitation of this study is that it might be challenging to compare the results with previous studies since the current study included only females in the sample.

Almost all previous studies (Geisler et al., 2010; Krygier et al., 2013; Sloan et al., 2017; Wang et al., 2013) included both genders. However, there are good methodological reasons for only using females as participants. Using only females reduces heterogeneity also potential gender confounds, such as variability in HRV between males and females (Koenig & Thayer, 2016). Moreover, this study does not provide a general picture of the relationship between SWB and HRV because the participants were within a limited age range.

Recommendations for Future Research

Research concerning SWB and HRV is still in its infancy, with few studies and ambiguous results. Existing studies have revealed some positive correlations between SWB and HRV, whereas others found a negative relationship. The first recommendations for future research would be to conduct studies that control various possible factors affecting SWB (e.g., personality style, age, culture) and factors affecting HRV (e.g., BMI, age, cardiac condition, smoking, exercise activity, and respiratory rate).

Furthermore, since there are several ways to measure HRV, another idea for future research is to look into whether the different measurements and data processing are comparable. For example, the autoregressive and fast Fourier transform model are assumed to be comparable; however, they do have different distinctive features (Berntson et al., 1997). Additionally, future research might as well review definitions of concepts, such as HF-HRV and RSA. Having two concepts that are often used interchangeably but are two different things (Billman, 2011) can mislead or form the basis of incorrect interpretations and assumptions.

Moreover, HRV is assumed to index the activity of the autonomic nervous system (Acharya et al., 2006), and the Neurovisceral Integration model proposes that further activation from the parasympathetic nervous system leads to higher HRV, which is associated with greater Well-being (Thayer, 2009). Moreover, the Neurovisceral integration model also suggests that the prefrontal cortex regulates emotions. Therefore, it would be interesting if future research investigates the link between cognition- and emotion regulation are related to HRV. One idea is to study if or how HRV can be a helpful tool when engaging in interventions that can positively affect SWB, such as emotional regulation.

Continued thoughts on future research are that positive affect seems to both increase and decrease HRV (Kreibig, 2010), and some studies found positive correlations between positive affect, while some did not. The different results could indicate that the sympathetic nervous system is also involved in the experience of SWB. For example, Neumann and Waldstein (2001) have noticed a relationship between happiness and sympathetic activation. However, if so, assessing HF-HRV alone is not enough to calculate SWB. Hence, there could be a need to measure the sympathetic nervous system and review the ratio between the two systems.

Another idea for future research, based on how emotions affect HRV (assuming a relationship between SWB and HRV), could be to investigate how different types of positive emotions affect HRV. This idea bases on Kreibig's (2010) article, where she suggests that joy (described as feelings of elation) increases HRV, whereas happiness decreases HRV. However, before implementing such research, it is essential to examine how different emotions should be described and measured. For example, the feeling of joy is described in some research as a feeling of its own (Kreibig., 2010), and other research included in the concept of happiness (e.g., Lyubomirsky et al., 2005).

Conclusion

Investigating the relationship between SWB and HRV is in its infancy. Nonetheless, it is an exciting topic, and I think it should be further studied to investigate the complex relationship between the brain and the body. However, there is a need for additional correlational studies and longitudinal within-subject designs since HRV and SWB are individual elements and should be compared to the individuals themselves. From this investigation, SWB did not correlate with HRV. Still, previous studies have found significant correlations, although with varying results.

It is crucial to keep in mind that all previously mentioned studies, including this one, are correlational studies. Nevertheless, correlational studies are essential at the beginning of a new research field. Correlational studies indicate how variables correlate and help researchers design proper interventional studies (Graziano & Raulin, 2013).

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Appendix

Heart rate variability analysis

The R–R interval data were collected using Firstbeat Bodyguard 2 measurement device (Firstbeat Technologies Ltd, Jyväskylä, Finland) detecting the R-peaks from the ECG signal (Parak et al. 2013). The data was then analyzed using Firstbeat Analysis Server software (version 7.5). Heart rate variability analysis was performed by calculating the second-by-second HRV indices using the short-time Fourier transform method. The software includes a powerful artifact correction feature for irregular ectopic beats, and signal noise (Saalasti et al. 2004). The consecutive artifact-corrected R–R intervals were then re-sampled at a rate of 5 Hz by using linear interpolation to obtain equidistantly sampled time series. From the re-sampled data, the software removes low-frequency trends and variances below and above the frequency band of interest using a polynomial filter and a digital FIR band-pass (0.03–1.2 Hz) filter. The analyzed variables included heart rate (bpm), and frequency-domain HRV variables including HF power (ms^2, 0.15–0.4 Hz), LF power (ms^2, 0.04–0.15 Hz), LF/HF ratio as well as time-domain HRV variables including RMSSD (ms), SDNN (ms), NN50 (N), and pNN50 (%).

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