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Respiratory Sinus Arrhythmia in Athletes, the Young, and the Old

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ABSTRACT

Respiratory Sinus Arrhythmia (RSA) is associated with and or explains many physiological processes that occur in the human body. In recent years RSA is now being recognized as an indicator of the body's efficiency in maintaining homeostasis and flexibility of the body's response to environmental demands [1]. It has also been reported that lower resting RSA in adolescents is associated or that it is a predictor of higher smoking rates and nicotine dependency 5 years later [2]. Respiratory sinus arrhythmia plays a role in many physiological body functions and this review seeks to explore the significance of RSA and how it varies from the early developmental stages, during adolescent period, during adulthood to mid-life stages, to the late senile stages of life, and in athletes compared to the general population.

Introduction

Heart rate variability as denoted by RSA is suggested to physiologically regulate emotion and so a study of resting RSA was conducted during early development in a high-risk population of low-income Mexican American where emotional regulation is critical [3]. This study found that resting RSA on average increased as infants aged and in fact this increase was accelerated over time between the ages of 6 weeks and 2 years of age [3]. Huffman and coworkers [4] showed that infants with higher resting RSA are easier to sooth compared to infants with low RSA. Furthermore, the behavior of infants with higher RSA is less withdrawn, depressed, or aggressive [5]. In a study of RSA during exercise in aerobically trained and untrained college-age males, it was reported that RSA consistently decreased during absolute exercise at heart rates above 100 beats per minute and in progression, RSA increased during the recovery phase [6]. It was further reported by Hatfield and coworkers that RSA can be detected during exercise and recovery and that RSA has a similar relationship to heart rate and metabolic state in both aerobically trained and untrained individuals.

In a study comparing autonomically mediated cardiovascular responses to certain maneuvers among health old men and women (60 – 80 years), middle aged (about 45 years old), and young adults (about 25 years old), it was reported that RSA and heart rate together with other factors were significantly attenuated in the old age group [7]. It has also been reported that heart rate variability associated with aging is determined by decreased amplitude of high frequency oscillations in heart rate which are attributed to RSA as well as by decreased amplitude of low frequency oscillations attributed to Meyer waves and very low frequency oscillations that may be attributed to thermoregulation although this is uncertain [8].

RSA in Early Developmental Stages

In an experiment of an auditory oddball task involving boys in 3 age groups: 5-, 7-, and 9-year-olds that examined aspects of heart rate variability as indicated by RSA, among other factors, it was reported that RSA, regardless of age group, was decreased during the performance of the oddball task compared to baseline levels [9]. These studies generally show a decrease in heart rate in anticipation of the target tone and this is consistent with studies done in adults. Several studies have shown that heart rate variability, which is indicative of RSA, is associated with tasks that require

attention during information processing [10-12] stemming from the groundwork research by Lacey & Lacey [13,14]. Respiratory sinus arrhythmia was investigated as a predictor of treatment outcome for young children with a mean age of 37.8 months who were born prematurely at less than 37 weeks gestation period [15].

Children with low baseline RSA were found to have more robust improvements in child disruptive behavior following treatment with Parent-Child Intervention Therapy [15]. This study concluded that children with lower capacity for emotional regulation benefited more (better treatment outcome) from treatment than children with higher capacity for emotional regulation. Since previous studies have generally indicated that higher levels of baseline RSA are associated with various positive psychological states such as empathy and sustained attention while low levels of baseline RSA are associated with less optimal psychological states such as higher externalizing behavior problems [16-19]. Thus, the Bagner and coworkers' study [15] suggests that children who have poor emotional control benefit more from treatment than children with good emotional control. This makes sense because it is easier to manipulate with treatment children who are not able to regulate their emotions well as opposed to children who are better able to regulate their emotions.

RSA in Adolescents

Low RSA which is indicative of low cardiac vagal control is usually associated with clinically depressed adults [20] as well as with infants of depressed mothers. A study investigated developmental patterns of resting RSA in 5 – 14 year-old children split into 2 treatment groups: the first children at high risk of depression (as a result of having a parent with a childhood-onset mood disorder) and the second children at low risk for depression [21]. The findings of this study indicate low risk children and not the high-risk children demonstrated a trajectory of RSA that significantly increased with age [21]. Once again low RSA is linked to an adverse physiological and/or psychological condition. The physiological processes and bodily phenomena that are associated with RSA are endless and are constantly being discovered and reported by scientists.

Respiratory sinus arrhythmia, in recent years has been reported to indicate how well the body maintain homeostasis and the body's flexibility in the manner by which it responds to environmental insults or demands [1,22,23]. The adverse effects of smoking on health are well documented. Smoking has multiple and devastating effects on cardiac health including increased risk for myocardial infarction [24] and pronounced dysfunction in cardiac blood vessel dilation which is a primary indicator of atherosclerosis [25]. This is why non-invasive cardiac health indicators such as RSA are of paramount importance in addressing the negative effects of smoking. In adolescents, smoking was reported to significantly lower resting RSA and elevated mean heart rate [1]. Furthermore, adolescents who began smoking much earlier in life around ages lower than 8 or 10 years old, exhibited higher decrease in RSA during their smoking session compared to those who attempted smoking at ages after 10 years old [1]. These findings are consistent with those reported in adults.

RSA in Young Adults

Substantial development of the autonomic nervous system, in utero, mostly occurs in the third trimester of gestation and as such the functioning of the autonomic nervous system may be different in adults who were born prior to attaining 28 weeks of gestation age [26]. To this end, Mathewson [26] conducted a study in which RSA and resting heart period were assessed in extremely low birth weight (less than 1,000 g) survivors and in normal birth weight controls at age ranges of 22 – 26 years old and again at 30 – 35 years old. The resting heart period denotes cardiac efficiency while RSA denotes responsive cardiac control by the autonomic nervous system. It was reported that resting RSA was significantly lower in the extremely low birth weight group compared to the normal birth weight group each time measurements were taken. Furthermore, over time, the individual differences in RSA among the extremely low birth weight participants were poorly preserved [26]. These findings suggest the parasympathetic functioning in extremely low birth weight survivors may start to decline prematurely before reaching old age.

In the United States there has been an increase of 24% in suicide between 1999 and 2014 such that suicide is presently the second leading cause of death for people ranging in age from 10 to 34 years old [27]. Suicide attempts happen across a broad range of underlying conditions or diagnoses and at times even in the absence of one [28]. Among those who attempt suicide, there are likely emotional or behavioral deficits and thus Tsypes and coworkers [28] conducted a study investigating potential differences in resting RSA in a large group of women (112) with varying diagnoses and with (n=56) or without (n=56) a history of suicide attempts who were matched on a wide range of demographic and clinical variables. After controlling for the effect of women's history of psychiatric diagnoses and their symptoms of depression and anxiety at the time, the study reported significantly lower resting RSA in women with a history of suicide attempts compared to women without a history of suicide attempts. This just goes to show that RSA may very well be the single measure in humans that can be used to determine health and wellbeing psychologically and physiologically, in fact universally.

RSA in Senile Adults

Cardiovascular responses that are controlled by the autonomic nervous system were measured in 15 old men and women in the age range 60 – 80 years old and compared to measurements in health young (about 25 years old) and middle-aged (about 45 years old)

to elucidate the effects of age [29]. Respiratory sinus arrhythmia and heart rate among other variables were significantly lowered at the old age group compared to the 2 younger age groups. Up to age 60 years old, only a transient decrease in autonomic cardiovascular responses was observed but there seems to be a precipitous decline in autonomic cardiovascular responses after age 60 years old [29]. Kaijser & Sachs [29] concluded that this decline in autonomic nervous system function wasn't merely due to some random dysfunction of a peripheral autonomic nerve but rather due to the receptor organ itself or multiple combined dysfunction of several parts of the autonomic nervous system in old age.

It has been demonstrated that with age, the decline in cardiac parasympathetic neural control is intimately associated with the reduction in arterial baroreflex gain [30]. Hunt and coworkers [31] reported that this decline in cardiac parasympathetic neural control can be mitigated by regular physical activity. These observations suggest that the decline in cardiac vagal control (and hence RSA as well since RSA indicates cardiac vagal control) may actually result from the deteriorating physical fitness that occurs with age [32]. In a study testing the effects of chronic aerobic exercise on age-related deterioration in cardiac parasympathetic receptor function, 44 young and old, fit and unfit subjects' parasympathomimetic responses to low doses of atropine were measured to simulate cardiac cholinergic receptor responses [33].

Changes in heart rate variability in this study were not always aligned with the chronotropic responses within subjects. However, as hypothesized, the basal RR intervals of subjects in the fit groups was longer than that of subjects in the unfit groups regardless of age [33]. Longer RR intervals equate to higher RSA values. Investigators also noted that the extent of RR interval lengthening with parasympathomimetic atropine was not affected by physical fitness and was significantly less in all older individuals. This suggests that exercise mitigates rather than abolish the effects of aging on cardiac vagal control.

RSA in Athletes

During acute exercise, Mitchell [34] explained that the change in heart rate occurs as a result of increased sympathetic tone with a concomitant decrease in parasympathetic tone. It is now broadly accepted that at 100 beats per minute during exercise, the parasympathetic nervous system almost completely loses control of the heart [35]. Additionally, it is thought that the parasympathetic nervous system, after assessment of afferent nervous signals, modulates heart rate so that oxygen delivery sufficiently meets metabolic demand [36]. This 'vagal brake' on heart rate, according to the Polyvagal Theory, quickly withdraws to accommodate increased cardiac output during exercise and in similar fashion resumes control to modulate cardiac output during recovery [6]. Hatfield and coworkers [6] in their study measured RSA during exercise in aerobically trained (athletes) and untrained men. They reported that RSA generally always decreases during absolute exercise at heart rates above 100 beats per minute and gradually increased during recovery.

During exercise heart rate is maximal at both inspiration and expiration so that cardiac output matches the high metabolic demands of the muscles hence RSA is decreased. Conversely during recovery, the difference in heart rate during inspiration and expiration is greater and thus RSA is increased. It is well established that the electrocardiograms of athletes are different from those of the general population which is based on the structural, physiological, and electrical changes that occur in the heart as a result of regular and continuous physical exercise over extended periods [37]. Hence it follows that RSA in athletes is different from that of the general population.

In a study investigating differences in male athlete electrocardiograms versus female athlete electrocardiograms, it was reported that female athletes had significantly higher resting heart rates compared to male athletes; 67 beats per minute versus 61 beats per minute [38]. Corici, et al. [38] also found that sinus bradycardia (heart rate of less than 50 beats per minute) occurred more frequently in male athletes while sinus arrhythmia (irregular heartbeat that is either too fast or too slow) occurred more frequently in female athletes. These differences between male and female athletes suggest that male and female athletes have different RSA as well.

Summary

Respiratory sinus arrhythmia as a marker of health, youth, and physical fitness indicates that higher values at rest are associated with these attributes whereas lower values are associated with their absence or lack thereof. This basic observation therefore means the greater the difference in heart rate during inspiration and heart rate during expiration is, the younger, healthier, and more physically fit an individual is in general. What does this really mean physiologically? Is it that younger, healthier, and more physically fit individuals have better cardiac autonomic control and thus more efficiently match ventilation, cardiac output, and metabolic demand? Answers to these questions may help us to increase our understanding of health and fitness in terms of how we can best manipulate them to our advantage. Respiratory sinus arrhythmia explains or is associated with almost all physiological processes in the human body including aging that any time spent studying and analyzing this phenomenon is time very well spent and contributes tremendously to the wealth of knowledge already amassed on the human body.

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