EFFECTS OF EIGHT WEEKS PHYSICAL TRAINING ON PHYSICAL PERFORMANCE AND HEART RATE VARIABILITY IN CHILDREN

Liisa Kraama

ABSTRACT

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Physical activity and aerobic capacity have decreased among children and adolescents during the last decades. Physically active adults have been shown to have higher heart rate variability (HRV) than less active adults. In adults training-induced changes in physical performance have been shown to be related to increase in HRV, especially in high frequency component (HF), which is a marker of parasympathetic activity. The purpose of this study was to examine, if the physical activity level of secondary school pupils is associated with the functions of the autonomic nervous system and if 8 weeks of instructed physical training could improve both the physical performance and cardiac autonomic function in children. The functions of the autonomic nervous system were measured by heart rate variability.

The test group had 12 girls and 12 boys and the control group 7 girls and 7 boys. All the subjects were 13-15 years old pupils. Physical training included warm up (10min), circuit training (20min), endurance training (running and playing 20-30 min), stretching and relaxing (10 min) 3 times a week for eight weeks. Intensity during endurance training was 70-75% of maximal heart rate. The following measurements were done both before and after the physical training period: endurance test (running tests starting from 7km/h and increasing by 0.2 km every 30 s), flexibility test (sit and reach), speed (30m sprinting) and power (3kg medicine ball throwing, standing long jump) tests. The low frequency (LF) and high frequency (HF) components of HRV were also measured in supine rest and in standing conditions before and after the eight weeks period as well as body mass, body mass index, fat percentage and skeletal muscle mass.

Time to exhaustion in the endurance test increased in the test group ($p<0.001$) and did not change in the control group. Flexibility and ball throwing improved in the test group ($p<0.05$) while no changes were observed in the control group. Although LF/HF in standing condition decreased ($p=0.114$) and HF increased ($p=0.187$) slightly in the test group, no significant changes were observed in HRV variables in either group. Neither were there any significant correlations found between HRV and endurance parameters.

Increased instructed physical training was clearly beneficial as shown by many improved performance parameters in the test group. Even though endurance capacity increased and slight changes were seen in LF/HF and HF in the test group, the association between was not as clear as earlier seen among adults. In conclusion, eight weeks physical training improves adolescents' physical performance, but it does not affect autonomic cardiac function.

Keywords: adolescents, endurance exercise, heart rate variability

TIIVISTELMÄ

Kraama, Liisa. 2013. Kahdeksan viikon fyysisen harjoittelun vaikutus lasten fyysiseen suorituskykyyn ja sydämen sykevaihteluun. Jyväskylän yliopisto, Liikuntabiologian laitos. Liikuntafysiologian Pro gradu –tutkielma. 52 s.

Lasten ja kasvuikäisten nuorten fyysinen aktiivisuus ja aerobinen kapasiteetti ovat vähentyneet viimeisten vuosikymmenten aikana. Fyysisesti aktiivisilla aikuisilla on todettu olevan enemmän sydämen sykevaihtelua kuin vähemmän aktiivisilla. Aikuisilla on harjoittelun aikaansaamien fyysisen suorituskyvyn muutosten todettu olevan yhteydessä sykevaihtelun, erityisesti parasympaattista aktiivisuutta kuvaavaan korkean taajuuden sykevaihtelun, kasvuun. Tässä pro gradu -tutkielmassa oli tarkoitus selvittää, voiko kahdeksan viikon ohjattu fyysinen harjoittelu parantaa lasten sekä fyysistä suorituskykyä että sydämen autonomisia toimintoja.

Testiryhmässä oli 12 tyttöä ja 12 poikaa ja kontrolliryhmässä 7 tyttöä ja 7 poikaa. Kaikki osallistujat olivat 12–15 vuotiaita koululaisia. Fyysiseen harjoitteluun kuului lämmittelyä 10 min, kuntopiiriharjoittelua tärkeimmille lihasryhmille 20 min, aerobista kestävyysharjoittelua 20–30min (pallopelejä, hölkkää) ja lopuksi venyttelyä ja rentoutumista noin 10min. Ohjattua harjoittelua oli kolme kertaa viikossa kahdeksan viikon ajan. Kestävyysharjoittelun teho oli 70 - 75 % maksimisykkeestä. Seuraavat mittaukset tehtiin ennen ja jälkeen harjoittelujakson: kestävyyskuntotesti (juoksua ensin 7 km/t ja vauhtia lisätään 0,2 km/t aina 30s välein), liikkuvuus- ja notkeustesti (istuvillaan eteen kurkottaen), 30 m nopeustesti ja voimamittaukset (vauhditon pituushyppy ja 3kg kuntopallon heitto). Sykevaihtelun matala (LF) ja korkea (HF) taajuus mitattiin sekä seisoma- että makuuasennosta. Paino, painoindeksi, lihasmassan määrä ja kehon rasvaprosentti määritettiin myös ennen harjoittelujaksoa ja sen jälkeen.

Testiryhmällä kestävyyskuntoa mittaavaan sukkulajuoksun aika piteni (p<0,001). Aika ei muuttunut kontrolliryhmällä. Notkeus ja pallonheitto paranivat testiryhmässä (p<0,05), mutta kontrolliryhmässä ei tapahtunut muutoksia. Vaikka testiryhmän LF/HF seisoma-asennosta mitattuna laski (p=0,114) ja HF nousi (p=0,187) hiukan, mitään merkittäviä muutoksia ei havaittu kummassakaan ryhmässä. Kestävyystulosten ja sykevaihtelumuuttujien välillä ei löydetty merkittäviä korrelaatioita.

Ohjatun fyysisen harjoittelun määrän lisääminen oli selvästi hyödyllistä, mikä käy ilmi testiryhmän parantuneista suorituskykyarvoista. Vaikka testiryhmän kestävyyskyky parani ja pieniä muutoksia havaittiin myös sykevaihteluarvoissa, niiden välinen yhteys ei ollut yhtä selkeä kuin mitä aikuisilla on havaittu.

Avainsanat: kasvuikäiset lapset, kestävyysharjoittelu, sydämen sykevaihtelu

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1 INTRODUCTION

During the last decades elementary and middle school pupils' physical activity and physical performance have been decreasing. It has also been shown that even though most of the students are motivated toward physical activity, their level of physical activity decreases across time (Yli-Piipari 2011). Regular physical activity has several well-known benefits such as prevention of respiratory and cardiovascular diseases and overweight, and improving neuromuscular capability, coordination and balance. Increased coordination and balance help avoiding musculoskeletal injuries in daily activities. Rightly balanced and enjoyable physical activity may have a vital part in improving adolescents' health, well-being and educational attainment (Kantomaa 2010).

Physically active adults have higher heart rate variability (HRV) than less active adults indicating enhanced cardiac autonomic function (Davy et al. 1998). Furthermore, training-induced changes in physical performance have been shown to be related to increases in HRV, especially in high frequency (HF) component (Hautala et al. 2003). Increase in HF correlates positively with greater parasympathetic activity and thus smaller stress level (Dishman et al. 1999).

The purpose of this study is to examine, if physical activity and performance and function of the autonomic nervous system could be affected by eight weeks of instructed physical training in elementary and secondary school children.
This study and thesis is a part of a larger Finnish – Spanish research done in co-operation with University of Oviedo, Spain, IES Mar del Sur de Taraguilla -school (Cadiz), Spain, University of Jyväskylä, Finland and Kuokkala Comprehensive school, Jyväskylä, Finland.

2 AUTONOMIC NERVOUS SYSTEM

Homeostasis is maintained in the body by endocrine and nervous systems. The function of the endocrine system is via hormones and its responses take place more slowly than the responses of the nervous system, which has three basic functions: sensory, integrative and motor functions. The nervous system is divided into two anatomical subdivisions namely the central nervous system (CNS) containing the brain and the spinal cord and the peripheral nervous system (PNS) consisting of cranial and spinal nerves. Functionally, the nervous system is also divided into two parts: the somatic nervous system (SNS), which is voluntary and conscious and the autonomic nervous system (ANS), which is involuntary and unconscious for the most part (Tortora & Grabowski 1996, 332 - 333).

Autonomic nervous system's general visceral motor (efferent) neurons regulate the activity of smooth and cardiac muscles and certain glands. ANS sensory (afferent) neurons bring information from visceral organs and blood vessels into CNS. The ANS functions are regulated by centers in the brain, mainly by hypothalamus and medulla oblongata, which receive input from the limbic system and other regions of the cerebrum (Tortora & Grabowski 1996, 488).

In SNS, motor neuron's effect is always excitation leading to skeletal muscle contraction. When the nervous stimulation ceases, the muscle contraction ends. In ANS, general visceral motor neurons either excite or inhibit the effector tissue such as cardiac muscle, smooth muscle and glands. These activities are usually unconscious and automatic. Input from the general somatic and special senses, acting via the limbic system, may modify autonomic motor neuron responses. Motor neuron pathway in ANS consists of two motor neurons following one another. The first neuron cell body is in CNS. The synapse between the first and the second neuron is in autonomic ganglion. The second neuron then has its cell body in that ganglion and its axon extends directly from the ganglion to the effector (figure 1, page 8). The neurotransmitters in ANS are acetylcholine or norepinephrine (NE) (Tortora & Grabowski 1996, 488).
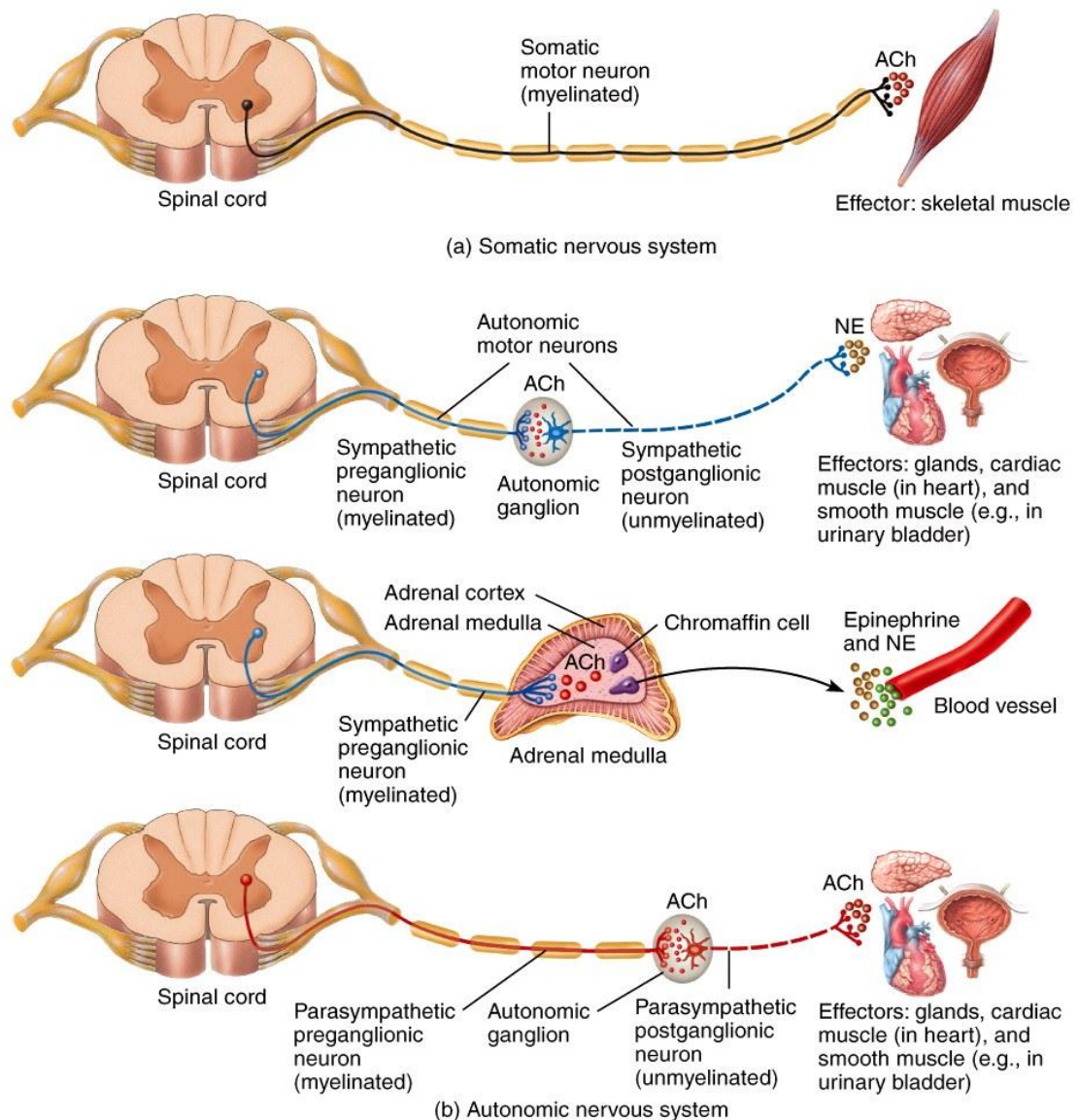
FIGURE 1. Comparison of somatic and autonomic nervous systems (Tortora & Derrickson 2009, 548).

The output part of ANS is divided into two divisions. Many organs have dual innervation, meaning that they receive impulses from both sympathetic and parasympathetic divisions. In general, nerve impulses from one division stimulate the organ to start or increase the activity (excitation), whereas impulses from the other one decrease the organs' activity (inhibition). For example, heart rate and contraction force are increased by the sympathetic nervous system and decreased by the

parasympathetic one. Dual innervation or only one division of autonomic system affecting an organ is possible, because both sympathetic and parasympathetic systems release different neurotransmitters, and the effector tissues have different neurotransmitter receptors. The balance between sympathetic and parasympathetic activity and tonus (impulse density) is regulated by the hypothalamus. Challenges and demands in internal and external environments can change this balance moment by moment. For instance, during great anxiety cerebral cortex can stimulate hypothalamus as a part of limbic system. Hypothalamus then stimulates the cardiovascular center (figure 2), which increases heart rate and contraction force and thus also blood pressure via sympathetic nerve fibers (Tortora & Grabowski 1996, 494 - 496).
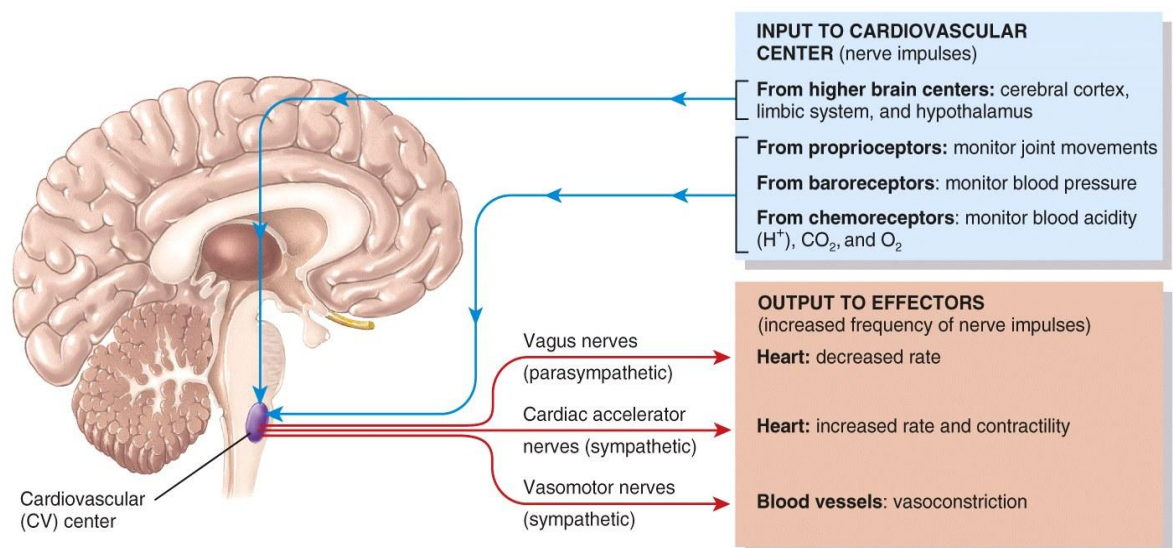
FIGURE 2. Nervous system control of the cardiovascular system (Tortora & Derrickson, 2009, 776).

The neurotransmitter in SNS neurons is acetylcholine. Such neurons are called cholinergic. In ANS all sympathetic and parasympathetic preganglionic neurons, some sympathetic postganglionic and all parasympathetic postganglionic neurons are also cholinergic. Most of the postganglionic sympathetic neurons' neurotransmitter is norepinephrine (noradrenaline) and such neurons are called adrenergic neurons.

The acetylcholine receptors in myocardium are called muscarinic receptors, and the epinephrine and norepinephrine receptors are called β – receptors (β_1) (Tortora & Grabowski 1996, 494).

3 HEART STRUCTURE, FUNCTION AND REGULATION

The cardiovascular system consists of the heart, blood vessels and blood. When our body is resting the heart pumps each minute about 5 liters blood to the lungs and the same volume to the rest of the body. At this rate, it pumps more than 14000 liters of blood in a day through an estimated 100 000 km of blood vessels. Since we are not resting all the time the actual flow is much larger. The more active the person, the greater the amount of blood the heart pumps (Tortora & Grabowski 1996, 579).

Heart muscle. Heart wall is formed of three layers: external layer called epicardium, middle layer called myocardium and the innermost layer called endocardium. Middle myocardium is cardiac muscle and is responsible for the pumping action of the heart. Cardiac muscle cells are involuntary, striated and branched (Tortora & Grabowski 1996, 581 - 582). There are three major types of cardiac muscle: atrial muscle, ventricular muscle, and specialized excitatory and conductive muscle fibers. The atrial and ventricular muscles contract similarly with the skeletal muscle, except the duration of the contraction being much longer. On the other hand, the specialized excitatory and conductive muscle fibers contract only weakly since there are only few contractive fibrils in them (Guyton & Hall 2006, 103). They are so called autorhythmic cells, which repeatedly and rhythmically generate action potentials. They set the rhythm for the whole heart and also form the conduction system, which enables the action potentials to spread around the heart muscle. Another difference between skeletal and the heart muscle is that in heart muscle the refractory period is absolute, meaning that a new contraction cannot begin during the refractory period and thus tetany (maintained contraction) is impossible (Tortora & Grabowski 1996, 590, 593). In the heart muscle, there is also an additional relative refractory period during which the heart muscle is able to contract, if the excitatory signal is very strong (Guyton & Hall, 2006, 105 - 106).

Heart muscle fibers swirl diagonally around the heart in interlacing bundles forming two independently working networks – an atrial and a ventricular network. Each fiber is in contact with neighboring fibers throughout the network by transverse thickenings

of the sarcolemma called intercalated discs. Within the discs there are gap junctions working as electrical synapses allowing muscle action potentials to spread throughout the fiber network. The entire atrial network then contracting as one unit and the ventricular network contracting as another one (Tortora & Grabowski 1996, 582).

We could also say that heart muscle is a syncytium of many cells thus forming an atrial syncytium and a ventricular syncytium. The atria are separated from the ventricles by fibrous tissue surrounding the area of valvular openings. This is the reason why electric potentials are not conducted from the atrial syncytium into the ventricular syncytium directly, but they are conducted only via specialized conductive muscle fiber cells. In this fibrous area between atria and ventricles the conductive system is called atrioventricular bundle, A -V bundle. Heart muscle being divided into these two syncytia allows the atria to contract a short time before the ventricles, and this is important for pumping effectiveness of the heart (Guyton & Hall 2006, 104).

Impulse conducting system. The autorhythmic cells (self-excitable cells) mentioned earlier form the impulse conducting system of the heart. When this system functions normally, the atria contract about one sixth of a second earlier than the ventricles. This phenomenon allows the ventricles to be filled in a greater extent. The conduction system also allows all parts of the ventricles to contract almost simultaneously, which is essential for the most effective pressure generation in the ventricles (Guyton & Hall, 2006, 116).

The sinoatrial (SA) node in the upper part of the right atrial wall, is called the pacemaker of the heart, because each normal cardiac excitation begins there. From the SA node, each action potential spreads throughout the atria via gap junctions in intercalated discs of atrial muscle fibers, thus causing the atria to contract. The node action potential travels down the septum between the two atria to the atrioventricular (AV) node proceeding further to the atrioventricular (AV) bundle (bundle of His). The bundle of His is the only electrical connection between the atria and the ventricles. Then the action potential moves along the right and left bundle branches that proceed through the interventricular septum towards the apex of the heart. Finally, Purkinje fibers, which are large-diameter conduction myofibers, conduct the action potential first to the apex of the heart and then upward to the remainder of the ventricular

myocardium. About 0.20 s after the atria have contracted, the ventricles contract (Tortora & Grabowski 1996, 590 – 591). The phase when the two atria or the ventricles contract is called systole. The phase when the atria or the ventricles relax is called diastole. When the atria contract, the ventricles relax and vice versa. A cardiac cycle consists of both atria and ventricles contracting and relaxing (Tortora & Grabowski 1996, 594).

Heart rate. Normal heart rate is determined by dynamic interaction between the spontaneous cardiac impulses generated by the sinoatrial (SA) node and by the modifying influences of the sympathetic and parasympathetic nervous system on the conducting tissue of the heart. These modifying elements do not establish the fundamental rhythm. The rate of spontaneous depolarization of the SA node is itself affected by its metabolic state and in the longer term by hormonal influences (Tortora & Grabowski 1996, 589, 591, 599-600). Cardiovascular center (CV), which is often called the vasomotor center, located in the medulla oblongata, receives information from higher brain centers like the cerebral cortex, limbic system and hypothalamus (see figure 2 page 10). It also receives sensory information (input) from proprioceptors, which monitor movement and position of limbs and muscles, and from chemoreceptors monitoring blood chemistry, and from baroreceptors monitoring blood pressure. Parasympathetic vagus nerve, the X cranial nerve, maintains the normal resting heart rate. The vagal nerve fibers innervate the SA node, AV node and atrial myocardium. There are only a few vagal fibers distributed to ventricular muscles and so the parasympathetic activity affects mainly the atrial myocardium and has little or no effect on ventricular muscle contraction (Tortora & Grabowski 1996, 598-599, 626). This is the reason why vagal stimulation mainly decreases the heart rate and has hardly any effect on the strength of the contraction of the heart muscle (Guyton & Hall, 1996, 113). Maximal parasympathetic activity may slow down the heart rate 20 or 30 beats/min or even stop the heart temporarily. Acceleration of the heart rate is affected both by the inhibition of vagal influences and the stimulation of the sympathetic nervous system. Sympathetic nerve fibers affect the SA node, AV node and most parts of the myocardium. They speed up the rate of spontaneous depolarization of SA node thus increasing the heart rate. They also increase contractility of both atrial and ventricular myocardium (Tortora & Grabowski 1996, 598-599, 626). Changes in blood pressure and respiration alter the heart rate via

autonomic nervous system continuously. During expiration, there is a vagal parasympathetic effect on heart, and thus the heart rate slows down. During inspiration parasympathetic effect is inhibited (vagal effect is smaller) and thus heart rate is accelerated (Guyton & Hall, 1996, 148; Nienstedt et al. 1989, 193).

Cardiac output, preload and afterload. The pumping of the heart maintains constant circulation in every part of the body. The amount of blood the ventricles pump forward during one minute is called the cardiac output (CO). The amount of blood each ventricle ejects forward with each contraction, is called the stroke volume (SV). Thus the average CO is: CO (ml / min) = SV (ml / beat) x HR (beats / min).

Based on the formula above, we can well say that the total blood volume circulates through the pulmonary and through the systemic circulations during one minute. When the demands for oxygen in the body change, CO changes accordingly. Cardiac output can be changed by increasing or decreasing SV or HR or both. The stroke volume is regulated by preload, contractility of the heart chamber muscle fibers and afterload (figure 3 page 15). These three regulating factors ensure that the left and right ventricles pump forward equal amounts of blood. The preload tells about the tension or stretch on the myocardium right before systole. A synonym for preload is end-diastolic-volume (EDV). The afterload is the pressure the ventricle has to obtain before the aortic or pulmonary valves will open and the blood can be ejected forward from the ventricles (Tortora & Grabowski 1996, 597- 598).

Frank-Starling Law of the heart. The greater the stretching force on ventricular myocardium at the end of diastole, the greater the contraction force of the myocardial fibers during the systole. "The greater the preload (EDV), within limits, the more forceful the contraction" (Tortora & Grabowski 1996, 597).
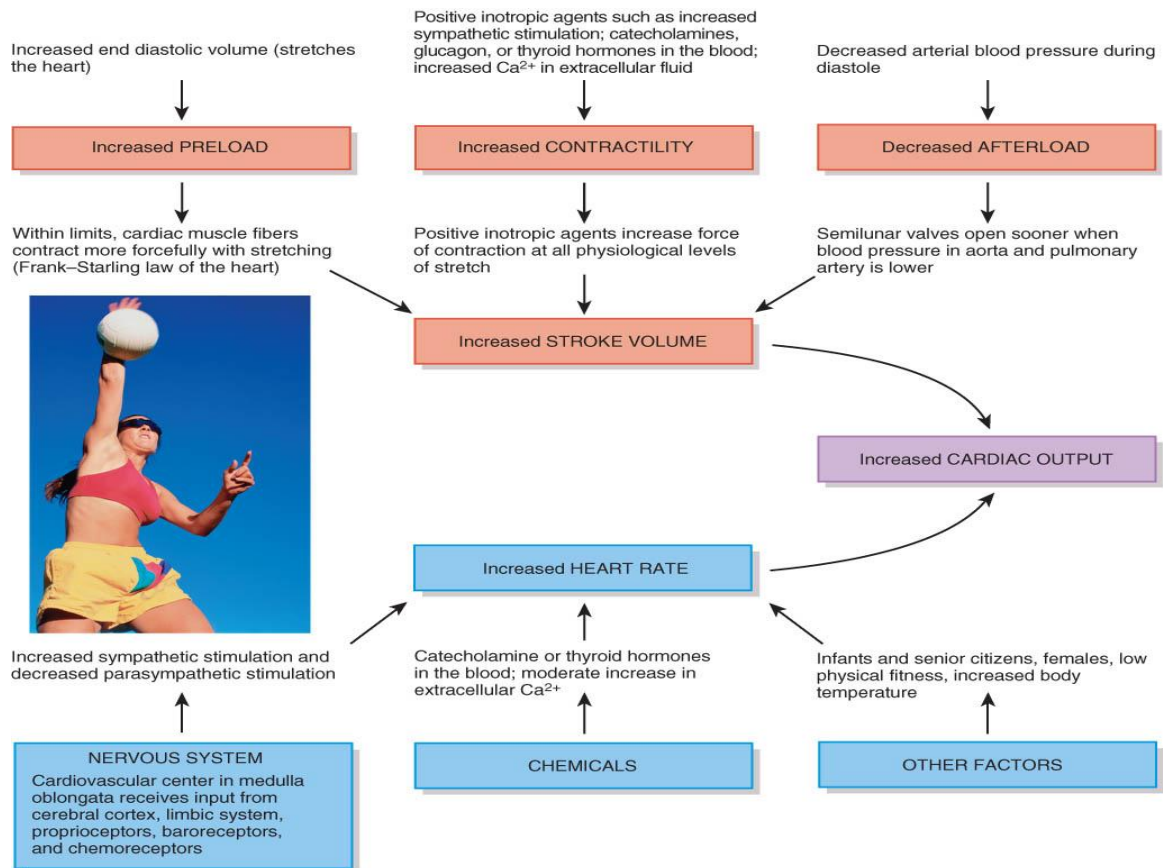
FIGURE 3. Factors increasing cardiac output (Tortora & Derrickson, 2009, 744).

Baroreceptors. Nerve cells, which respond to changes in pressure or stretch are called baroreceptors or pressoreceptors. They are located e.g. in the wall of the arch of aorta and in the wall of carotid sinus, a widening of the internal carotid artery just after it has branched from the common carotid artery (figure 4). Increasing blood pressure stretches the walls of the aorta and the carotid sinus stimulating baroreceptors. The carotid sinus reflex helps to maintain normal blood pressure in the brain and the aortic reflex affects general systemic blood pressure. Impulses from baroreceptors in carotid sinus go to the cardiovascular center in medulla oblongata via sensory fibers of glossopharyngeal (IX) nerve and from baroreceptors in the arch of aorta via sensory fibers of the vagus nerve (Tortora & Grabowski 1996, 626, Guyton et al. 1996, 209). Through cardiovagal baroreflex sensitivity (BRS) the heart rate slows down (prolongation of R-R interval) when there is a sudden, transient rise of systemic blood pressure (SBP). BRS can be defined as the relation between R–R interval and SBP. The slope of the R-R interval – SBP relation during this rise in SBP is used as a measure of cardiovagal baroreflex sensitivity (Smyth et al. 1969). Reduced

cardiovagal BRS is associated with impaired regulation of arterial blood pressure (BP) and in such cases there is also a possibility for more severe cardiac malfunctions. Cardiovagal baroreflex sensitivity (BRS) decreases with age but regular aerobic exercise may have positive effects on it. It is not well known what are the mechanisms of how aging reduces cardiovagal BRS and how regular aerobic exercise modifies such change. Monahan et al. (2001) found that "Age- and habitual exercise-associated differences in cardiovagal BRS are associated with corresponding differences in compliance of the carotid artery among healthy men."
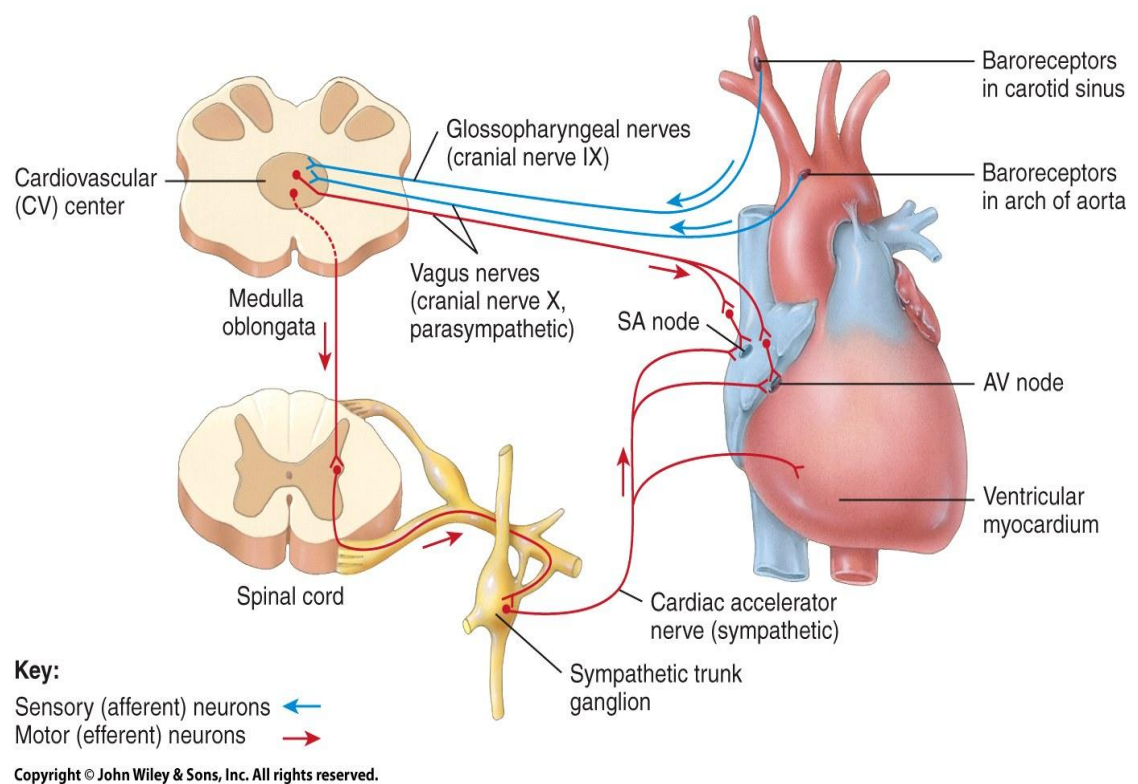

FIGURE 4. Innervation of the heart by the autonomic nervous system and baroreceptor reflexes (Tortora & Derrickson 2009, 777).

3.1 Heart rate variability

Heart rate variability (HRV) means the amount of fluctuations around the mean heart rate. Heart rate is the amount of R-R intervals in ECG during one minute. The lengths

of those R-R intervals vary – that variation is called heart rate variability. "It is the interval between consecutive beats that is being analyzed rather than the heart rate per se" (Task Force, 1996). Normally the variation of R-R intervals is between 0,4s -1,5s, meaning that heart rate normally varies between 40 and 150 beats / minute. During the night time endurance athletes' R-R intervals can be even longer (Sovijärvi et al.1993, 123). The variation is caused by the autonomic nervous system modifying cardiorespiratory function. It tells about the cardiorespiratory control system and thus it can be used when investigating the sympathetic and parasympathetic nervous system functions (Task Force, 1996). "HRV indices, determined either by time or frequency domain, are closely related and reflect parasympathetic, sympathetic, mixed sympathetic and parasympathetic and circadian rhythms" (Stein and Kleiger, 1999). HRV measurements are easy to perform, non-invasive, reproducible and reliable under standardized conditions, which are a necessity, since HRV is influenced by several factors e.g. respiration rate and posture. HRV measurements can be used for young and old and even to infants and fetuses (Finley and Sherwin, 1995).

Heart rate variability (HRV) is an essential method when studying exercise and fitness and their related issues e.g. response to aerobic training in healthy sedentary subjects and recovery after physical training (Kaikkonen et al. 2007). It is also a widely used method in evaluating and investigating various clinical issues like stress (Dishman et al.1999, Hall et al.2004), diabetic autonomic neuropathy (Vinik et al.2003, Howorka et al.1997) and cardiovascular diseases (Singh et al. 1998).

Physiology of heart rate variability. The main periodic fluctuations found in heart rate are respiratory sinus arrhythmia (Kawachi 1997) and baroreflex-related HRV (van Ravenswaaij-Arts et al. 1993).

Heart rate variability fluctuating with the phase of respiration is called respiratory sinus arrhythmia, RSA. While inhaling the R-R intervals are shortened and while exhaling they are prolonged. RSA is mainly caused by inspiration inhibiting the parasympathetic effect to the heart. Vagal effect to the SA-node occurs mostly during expiration and it is attenuated or inhibited during inspiration (Kawachi 1997). Inhibition of inspiration is primarily caused by central impulses from the medullary respiratory center to the cardiovascular center. RSA is also affected by hemodynamic

changes and thoracic stretch receptors. RSA can be overruled by atropine or vagotomy showing that it is parasympatheticly mediated (van Ravenswaaij-Arts et al. 1993) and so reduced HRV has been used as an indicator of reduced vagal activity. HRV is a cardiac measure found in ECG. From the ECG it is impossible to define the origin of reduced vagal activity, since it can be from the vagal centers of the brain or from the contribution of peripheral target organ or from the nerve impulses conducting pathways to or from the brain (Kawachi 1997). High frequency (HF) component in spectral analysis of HRV is mainly due to vagal efferent activity (Task Force, 1996).

Baroreceptors are sensitive to changes in blood pressure and stretch in arterial walls. As mentioned earlier, cardiovagal baroreflex sensitivity (BRS) causes the heart rate (HR) to slow down when there is a sudden, transient rise of systemic blood pressure (SBP). This parasympathetic effect on SA-node slowing down the HR causes SBP to decrease. If SBP decreases the baroreceptors are stretched less and send nerve impulses to cardiovascular center (CV) at a slower rate. The response of CV is to increase sympathetic activity and decrease parasympathetic activity on HR i.e. acceleration of heart rate (Tortora & Grabowski 1996, 626). The innervation of the heart by baroreceptor reflexes is shown in figure 4 page 16.

3.1.1 Effect of age to heart rate variability

Heart rate variability decreases with age. Finley et al. (1995) studied the HRV of children and adults ages between 1 month and 24 years. All the subjects were normal, healthy children and adults. The research was done by using 24-hour continuous ECG-recording so that times of quiet and active sleep and times when awake were all included. The results showed a clear age dependency of HRV. LF, HF and total power increased during $0 – 6$ years and decreased in all age groups older than 6 years (Finley et al. 1995). These results seem to show a gradual increase in parasympathetic activity when related to sympathetic activity in children ages from 1 month to 6 years. After 6 years the parasympathetic activity seems to gradually decrease. Autonomic nervous system activity affects both heart rate and heart rate variability. Age dependent changes in HRV may be related to the maturing process of vagal and sympathetic control of the heart. Also the changes in cardiac volume happening with growth from

early childhood to adulthood could be another possible influential factor on the age dependency of HRV (Finley et al. 1995).

Aging per se decreases HRV both in healthy sedentary and physically active women (Davy et al. 1998). A decrease in efferent vagal activity and reduced beta-adrenergic responsiveness is thought to be the reason for the HRV decline. Regular physical activity (which slows down the aging process) has been shown to raise HRV, presumably by increasing vagal tone (Kawachi 1997). Davy et al. (1998) showed that physically active women had higher HRV levels and baroreflex sensitivity when compared to sedentary women regardless of age. However, it is unclear whether the changes in BRS and intrinsic sinoatrial node function occur with primary aging (Davy et al. 1998). Age-related increase in systolic arterial blood pressure accounts for only about 10% of the variability in spontaneous cardiac baroreflex sensitivity (SBRS) and increased systolic blood pressure seems not be related to HRV at all (Davy et al. 1998).

3.1.2 Acute and chronic stress, sleep and heart rate variability

Various types of stress are very common today. There is e.g. mental stress, physical stress and exercise related overtraining stress. Hynynen et al. (2011) studied effects of both acute and chronic physical and psychological stress on sleep. They did not find differences in night time heart rate nor in HRV between overtrained and control athletes. The four main conclusions of the study were the following: 1) Acute physical stress affected sleep during the following night. The effects were seen in increased heart rate, decreased HRV, lowered parasympathetic regulation and slightly increased sympathetic reactivity. 2) Acute psychological stress did not affect night time HRV during the night before or after stressful situation. 3) Chronic physical or 4) high level psychological stress did not affect autonomic regulative functions during the sleep, but in the morning right after waking up a decrease in HRV and in parasympathetic regulations could be seen. In conclusion, acute physical stress and both physical and psychological chronic stress diminishes person's resources for future challenges (Hynynen, 2011).

There are earlier studies that have shown a link between autonomic modulation and sleep. In their study Hall et al. (2004) wanted to evaluate the impact of stress on HRV during sleep. They hypothesized that "stress would be associated with a decrease in parasympathetic modulation and an increase in sympathovagal balance throughout NREM (nonrapid eye movement) and REM (rapid eye movement) sleep" and that "stress-related changes in HRV would be associated with disrupted sleep". As a result, they concluded that acute stress alters HRV during sleep and is associated with a decrease in parasympathetic modulation and an increase in sympathovagal balance throughout sleep. Stress-related changes seen in HRV revealed changed functions of the autonomic nervous system. These changes were associated with small but important decreases in maintaining sleep and could be seen in the amount of wakefulness during sleep. Stress also affected deep sleep. "As a conclusion, stress-related changes in HRV may indicate a mechanism whereby acute stress disrupts sleep" (Hall et al. 2004).

3.1.3 The effect of persistent stress on HRV among physically fit men and women

 Dishman et al. (1999) examined the relationship between vagal modulation of HRV and persistent stress. They examined physically fit 92 healthy men and women. HRV was measured during 5 min of supine rest. Men and women taking part in the study evaluated how anxious characters they are and rated perceived emotional stress during past week. A weak inverse relationship between perceived emotional stress during the past week and vagal modulation of HRV was found. The result provides limited support for an attenuated parasympathetic modulation of HRV which may refer to an experience of emotional stress. It shows that the relationship between the HF component of HRV and experience of stress is independent of trait anxiety and cardiorespiratory fitness among physically active adults (Dishman et al. 1999).

These studies by Dishman et al. (1999), Hynynen et al. (2001) and Hall et al. (2004) dealing with stress, are important when considering the amount of different kinds of stress in today's society and the possible effects of it. Stress has an inverse relationship with vagal modulation of HRV. On the other hand, low HRV is associated

with cardiac arrhythmia, cardiac mortality, and all cause myocardial infarction (Task Force, 1996).

3.1.4 Effect of physical activity on heart rate variability

HRV can be used for instance when studying the effects of training in sedentary subjects (Tulppo et al. 2003), training responses (Hautala et al. 2003), recovery after different endurance exercises (Kaikkonen et al 2007) and effects of physical activity in different age groups (Davy et al. 1998). Endurance training can also be guided individually by daily HRV measurements (Kiviniemi et al. 2007).

Recovery after endurance exercise. Kaikkonen et al. (2007) studied HRV dynamics, especially vagal reactivation, during early recovery after different intensities and work loads of endurance exercises. They found out that HRV started to increase during the first 5 min of the recovery. The increased intensity of the exercise caused slower recovery high frequency power (HFP) and also lower HF and total power (TP) levels during the first 5 min of the recovery when compared to the low-intensity exercise. The doubled running distance (from 3500 to 7000m) at the intensity of 50 and 63% VO_{2max} had no influence on HRV during recovery.

Aerobic training response. Cardiovascular autonomic function correlates with the response to aerobic training in healthy sedentary subjects. Hautala et al. (2003) studied physiological background of the differences in the training responses, since individual responses to aerobic training vary from almost none to 40% increase in aerobic fitness in sedentary subjects. They tested the following hypothesis: "individual cardiac autonomic function may predict the response to aerobic training". They used time- and frequency-domain analyses of HRV methods. A significant correlation was observed between the training response and the baseline HF power (high frequency power) of R-R intervals analyzed over the 24-hour recording during the night time and daytime. Also LF (low frequency power) and VLF (very low frequency power) were related to the training response. After adjustment for age, only HF power was associated with the training response. HF power during the night time hours accounted for 27% of the change as an independent predictor of the aerobic training response. Large variation in

individual responses to aerobic training were mainly due to gender and age. Reasons for age affecting the responses might have been the large age range, 23-52 years, and the short 8 weeks training period (Hautala et al. 2003).

Physical activity, age and HRV. Physically active young and older adult women and their HRV were studied by Davy et al. (1998). They found out that HRV and spontaneous cardiac baroreflex sensitivity (SBRS) are higher in physically active women, at any age even though HRV and SBRS decline with advancing age in healthy sedentary women and also in healthy physically active women (Davy et al. 1998). Their finding of decline in HRV with age also in physically active women suggests that aging seems to have an important influence on HRV. This may have many possibilities for clinical and physiological applications, since reduced HRV is associated with a risk for several diseases. Physically active older women had higher HRV than their sedentary peers. That would suggest that physical activity even in older age reduces any HRV- associated disease and mortality risk. This study by Davy et al. (1998) included only a relatively small number of subjects and conformation of these findings in a larger population would be necessary to support the results.

3.2 Measuring and analyzing heart rate variability

Heart rate variability can be measured by ECG from the R-R intervals by using normal ECG recording or heart rate monitors. When statistical time domain or frequency domain methods are used, the complete signal should be carefully edited using visual checks and manual corrections of individual RR intervals and QRS complex classifications (Task Force 1996).

When investigating short-term HRV, 5-minute recordings are considered to be suitable unless the nature of the study requires differently. The investigation should always be planned so that the recording environment remains similar to each individual subject (Task Force 1996).

Frequency domain HRV analysis has been used when evaluating mental or physical stress. However, there are many situations, such as exercise, where heart rate changes

rapidly over time, making frequency domain analysis of HRV unsuitable, because the assumption of being stationary is not satisfied. Meanwhile, the investigation of these rapid changes in is of considerable interest. The time domain HRV index is suitable in assessment of dynamic change of stress. In the exercise related studies, it seems though that very often both time-domain and frequency domain measurements are being used. Heart rate variability is commonly described by the standard deviation of intervals between successive R - waves (SDRR) of the cardiac cycle. Short-term variation (e.g. measured during periods of several minutes) can be decomposed mathematically into spectral components which estimate autonomic modulation of heart rate. The high frequency (HF) spectrum (0.15 - 0.5 Hz) corresponds to vagally-mediated modulation of HRV associated with respiration i.e. respiratory sinus arrhythmia. The low frequency (LF) spectrum (0.05 - 0.15 Hz) corresponds to baroreflex control of heart rate and reflects mixed sympathetic and parasympathetic modulation of HRV, depending upon the circumstances of the assessment. When measured during slow, deep breathing or in the supine position, LF activity is believed to be vagally controlled (Pomeranz et al. 1985; Grasso et al. 1997).

Heart rate variability is considered to be reliable and to have great validity as a method when used to estimate autonomic nervous system functions. The sensitivity has to be evaluated according to the situation and character of the measurements taking place. And even though "HRV has considerable potential to assess the role of autonomic nervous system fluctuations in normal healthy individuals and in patients with various cardiovascular and non - cardiovascular disorders, large prospective longitudinal studies are needed to determine the sensitivity, specificity, and predictive value of HRV in the identification of individuals at risk for subsequent morbid and mortal events" (Task Force, 1996).

4 HEART RATE VARIABILITY AND PHYSICAL FITTNESS IN CHILDREN

Children between ages 1 month to 6 years seem to have gradual increase in parasympathetic activity relative to sympathetic activity seen in HRV. After 6 years of age HRV decreases. This seems to be due to the maturing process of the autonomic nervous system (Finley et al. 1995).

In an adult population, regular physical exercise has several beneficial effects on autonomic nervous system seen in HRV. Henje Blom et al. (2009) found, when studying a group of healthy adolescents, age range being 15 years 11 months - 17 years 7 months, that adolescents' HRV was related to their self-reported physical activity. Lifestyle factors like smoking, eating and sleeping habits did not have such effect. Since they wanted to evaluate the stability of the intra-individual HRV, they repeated the same measurements twice, the second ones 6 months after the first ones. In conclusion, it is appropriate to summarize that the effects of regular physical activity both in adults and in adolescents are similar: enhanced parasympathetic activity.

Prepubescent children trained for a period of seven weeks, three 30 minutes session a week. Training sessions happened in different times during each week depending e.g. on school schedule. The training intensity was determined for each child according to their own maximal aerobic velocity (Gamelin et al. 2009). Gamelin et al. (2009) took great care to standardize the conditions according to the recommendations by Winsley et al. (2003). Despite the great increase in aerobic fitness, the effects on the autonomic nervous system were not significant (Gamelin et al. 2009). The children still being immature in their growth and in nervous system sensitivity as well as the short time period of the research could have affected the results (Gamelin et al. 2009, Henje Blom et al. 2009).

Reliability of heart rate variability measures at rest and during light exercise in children were studied by Winsley et al. (2003). Before this research, there was no

known published data on the reliability of the short term resting HRV measures in healthy children. Thus there is a need to establish reliability to evaluate the use of HRV technique and measures with young people during exercise. In their conclusion, Winsley et al. (2003) suggested tighter control of extraneous influences – often children do not remember their previous physical activity nor how intensive the exercise was. It is also hard to make sure that all pupils who are coming to the measurements avoid caffeinated beverages, drugs etc. Their advice to the researchers is to be careful when using and interpreting HRV measures of children and young people.

In order to have reliable and repeatable research on children's physical activity and HRV, the following issues should be considered: children's age, the type of physical training and the length of each training period, total length of all training, the time of the day and outward conditions of HRV measurements staying the same, things that happened right before and on the previous day of the measurements (Winsley et al. 2003, Gamelin et al. 2009, Henje Blom et al. 2009).

5 PURPOSE

The purpose of this study was to examine if secondary school pupils' physical activity level is associated with the autonomic nervous system functions. Secondly, we wanted to examine, if the function of the autonomic nervous system and physical performance can be affected by eight weeks of instructed physical training in secondary school pupils.

The research problems of the present study are:

1. Is the physical activity level of secondary school pupils associated with functions of the autonomic nervous system measured by heart rate variability?
2. Can the function of the cardiac autonomic nervous system and physical performance be affected by eight weeks of instructed physical training?

The hypotheses of the present study are:
1. Physical activity level of secondary school pupils is associated with the autonomic nervous system functions. It has been shown that physically active adults have higher heart rate variability than less active adults (Davy et al. 1998). Adults' training-induced changes in physical performance have been shown to be related to increase in HRV, especially in its high frequency component.
2. Physical performance and the cardiac autonomic function of secondary school pupils are improved by eight weeks of instructed physical training. Hautala et al. (2003) were studying sedentary men and they found a significant positive correlation between the training response and HRV parameters.

6 METHODS

6.1 Subjects

Subjects were volunteer pupils between ages 13 − 15. The test group consisted of 12 girls and 12 boys and the control group of 7 girls and 7 boys. The tests took place in the Kuokkala Comprehensive School in Jyväskylä, Finland, where the participating pupils were studying. During school physical education classes, announcements were made about the research program. The pupils received information sheets to take home. The parents of the participating pupils were asked to give written approval for their child to be involved in the training program and in the measurements included in the study. In the same approval form, the parents also agreed that their child would not take part in training neither testing, if the child was sick (Appendix 1). The background information form filled by every participating pupil (Appendix 1), showed that pupils volunteering for the test group were physically active already before the eight weeks training period. The control group pupils did not have any special interest to go in for organized physical activities during their leisure time. Due to technical, personal and seasonal reasons the actual number of participants in HRV tests was 11 − 12 in the test group and 3 − 4 in the control group. After all the tests the pupils got a feedback sheet (Appendix 2). The procedures of the research were approved by the Ethics Committee of the University of Jyväskylä. The characteristics of the subjects before (1) and after (2) the training program have been described in Table 1.

TABLE 1. Characteristics of the study subjects (n= 37) before and after the training program

	Before		After	
Body mass (kg)	57.3	±9.1	58.2	±9.0
BMI	20.7	±2.8	20.9	±2.8
Fat %	19.1	±7.2	19.0	±7.5
SMM (kg)	25.4	±4.6	25.9	±4.7

Abbreviations: BMI = Body Mass Index, kg/m^2; SMM = Skeletal Muscle Mass

6.2 Study design

The first body composition and HRV measurements for the test group were done in March 2009 before the training period. The second measurements took place during the last weeks of May, after the eight weeks of training. The first measurements for the control group started also in March and continued until early April 2009. The second measurements for the control group were done during the last weeks of May 2009.

Physical training was carried out for eight weeks. During the first four weeks, the test group had three training sessions per week. During the latter four weeks, they had two training sessions per week due to some school holidays. Every time the training lasted for 60 minutes and included warm up for 10 minutes. The exercises included circuit training for 20 min and endurance training for 20 – 30 min. At the end of each session the students played e.g. floorball or basketball for relaxing for 10 min. Intensity during endurance training was targeted to be approximately 70 – 75 % of individual maximal heart rate.

6.3 Measurements

6.3.1 Physical fitness tests

The following seven tests were done before and after the eight weeks of physical training: sit and reach flexibility test, overhead 3 kg medicine ball throw (forwards), standing long jump test (broad jump), vertical jump test (using flight time), 10 x 5m shuttle test, 20m multistage fitness test (beep test) for endurance and 30 meters speed test (sprint test).

Sit and reach flexibility test. This test is a common measure of flexibility. The test specifically measures flexibility of the lower back and hamstring muscles (Ahtiainen 2010).

Overhead 3 kg medicine ball throw (forwards). The test measures upper body strength and explosive power (Kyröläinen 2010). The pupil is standing on one place holding the 3kg medicine ball overhead. The ball is thrown forwards and a step forward is allowed after the throw. The distance of the throw is measured from the front foot when standing to where the ball lands.

Standing long jump test. This test was used to evaluate explosive power of lower extremities (Kyröläinen 2010). The pupil places the feet over the edge of the sandpit, crouches a little, leans forward, swings the arms back- and forwards and jumps as far as possible, jumping with both feet into the sandpit. The jump starts from a static position. The length of the jump is measured, and the best of three jumps is recorded.

Vertical jump test. The vertical jump is used to measure the explosive power of extensor muscles of lower extremities (Kyröläinen 2010).

10 x 5m shuttle test. This is a test for speed and agility. Time used for the 50 meters run was measured (Ahtiainen 2010).

20m multistage fitness test (beep test). This test is commonly used as a maximal running aerobic fitness test. In multistage fitness test (MSFT), also called Leger's test (Leger & Lambert, 1982), athlete's score are time and final speed (km/h). The maximal time in MSFT is possible to convert to a VO_{2max} equivalent. Correlation with actual VO_{2max} scores is high, so the validity of the test is good. Reliability of MSFT depends on how strictly the test is run and how much practice is allowed for the subjects before the actual testing. Progressive aerobic test was used to measure endurance. In this test, the pupils were running in the beginning at the speed of 7 km/h, and every 30 seconds the speed increased by 0,20 km/h. The maximal speed was measured.

30 meters speed test (sprint test). Sprint or speed tests can be performed over varying distances depending on the factors being tested. The present pupils were tested on 30 meters test with running time being measured at 10 and 30 meters.

6.3.2 Body Composition

Before and after the eight weeks training period body weight, fat % and skeletal muscle mass (SMM) and body mass index (BMI) were measured by a bioimpedance device (Biospace, InBody720, Seoul, Korea). Pupils' height was measured during the first measurements. The tests took place at the Kuokkala Comprehensive School according to previously planned schedule, always before lunch time.

6.3.3 Heart rate variability measurements and analysis

Heart rate variability (HRV). Measurements were done by using Polar S810i heart rate monitor (Polar Electro, Polar, Kempele, Finland). The pupils waited for their own turn for measurement about ten minutes calmly and quietly sitting in the waiting room. They had been advised not to do any sports or drink coffee or any kind of caffeine drinks before the tests. After the waiting period, the pupil entered into the quiet and dimly lighted measurement room. Before HRV was measured, the pupil laid down on a bed for few minutes. Heart rate belt was put at its place around the pupil's chest. The actual HRV measurement including orthostatic test lasted about 10 minutes: the first five minutes the pupil was on a supine position, then when told he or she stood up and remained standing for the last five minutes. During the test, any extra movement or anything disturbing and the time of the disturbance were marked down. Later when the data was analysed, disturbances were excluded. After each test, the data was saved on a computer under the identification number given to each pupil.

Heart rate variability analyses. Firstly, the HRV data was opened to computer by the First Beat Pro –program (First Beat Technologies, Jyväskylä, Finland). The MATLAB (MathWorks, version 9.x.x) –program was used to calculate HRV parameters and to remove artefacts from the analysed data. After this the material was checked manually and the remaining ectopic beats and unclear data was removed. From the total 10 minutes recording time, two minutes before the pupil stood up and three minutes after the orthostatic reaction were included in the analysis. Analyzed variables included: heart rate and maximal heart rate (HR and HR_{max}), R-R interval (RRI), root mean square of successive RRIs (RMSSD), the percentage fraction of consecutive RR

intervals that differ by more than 50 ms (pNN50), high frequency power (HF 0.15–0.40 Hz), low frequency power (LF 0.04–0.15 Hz), and LF/HF ratio in supine and standing positions.

6.4 Statistical methods

The data were analyzed using SPSS software. Standard statistical methods were used for the calculation of means and standard deviations. The results are expressed as mean ± SD. To meet the assumptions of parametric statistical analysis, a natural logarithm transformation of the LF supine and standing, HF supine and standing, LF/HF supine and standing values was used. The normal Gaussian distribution of the data was verified by Shapiro - Wilks test. In all statistical tests, differences were significant when $p < 0.05$. Sphericity of data for two-way repeated measures (ANOVA) was tested using Mauchly's test of sphericity. Two-way repeated measures (ANOVA) were used to test the statistical differences in physical performance tests between the test and control groups after the physical training period. Correlations between pupils' endurance performance and ANS function before physical activity period was carried out by the Pearson two-tail correlation test combining the test and the control groups together.

7 RESULTS

7.1 Body mass, body mass index, fat percentage, skeletal muscle mass

Body mass. Body mass (BM) did not change significantly. The test group's (n=26) BM before training was 57.1 ± 9.2kg and after training 58.1 ± 9.1kg. The control group's (n=11) BM in the first measurement was 57.9 ±9.3kg and in the second measurement it was 58.6 ± 9.4kg. Mean change among all students (n=37) was 1.6±2.5kg.

Body mass index. There was no significant change in BMI in either group (figure 5). The test group's BMI was 20.4 ±2.5 kg/m^2 before the training period and 20.7 ±2.5 kg/m^2 ($p<0.1$) after. The control group's BMI when measured the first time was 21.6 ±3.5 kg/m^2 and in the second measurement 21.5±3.5 kg/m^2.
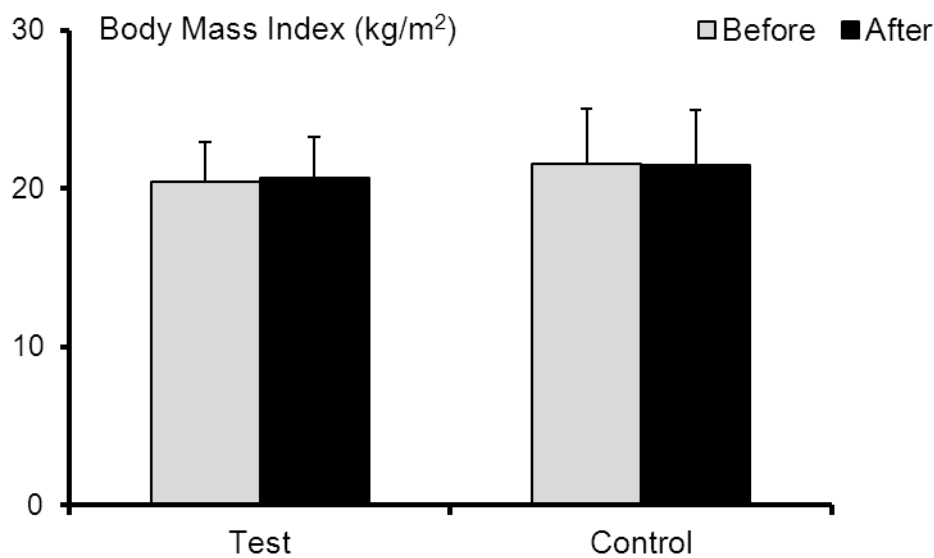

FIGURE 5. Changes in Body Mass Index before and after the 8-week training period in the test and control groups.

Fat percentage. Fat% did not change in the test group (17.2% ± 6.8% vs. 17.7% ± 7.4%) during the eight week training period (figure 6). Fat% decreased significantly in the control group from 23.7% ± 6.5% to 22.1% ± 7.1% ($p<0.01$).
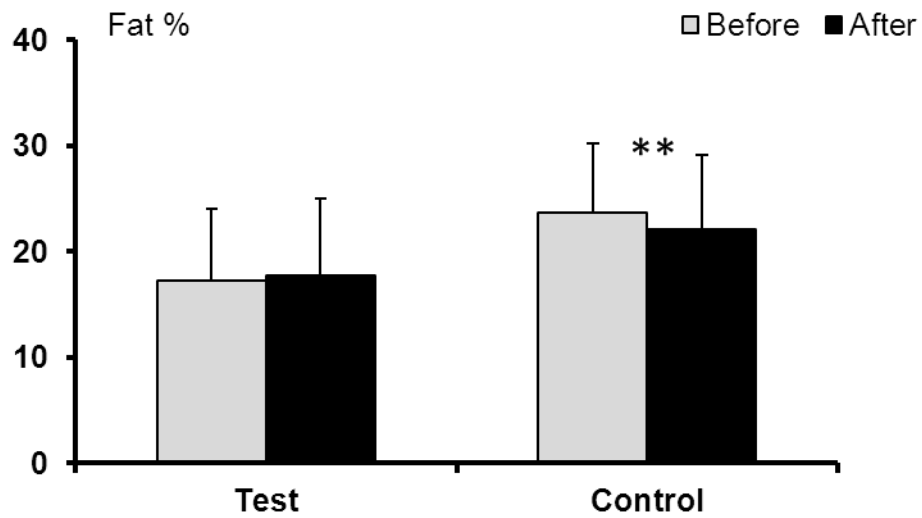
FIGURE 6. Changes in fat % before and after the 8-week training period in the test and control groups.

Skeletal muscle mass. SMM did not change in the test group 26.1 ± 5.2kg vs. 26.4 ± 5.3kg (p<0.1). SMM increased significantly in the control group from 23.9 ± 2.8kg to 24.8 ± 2.9kg (p<0.01).
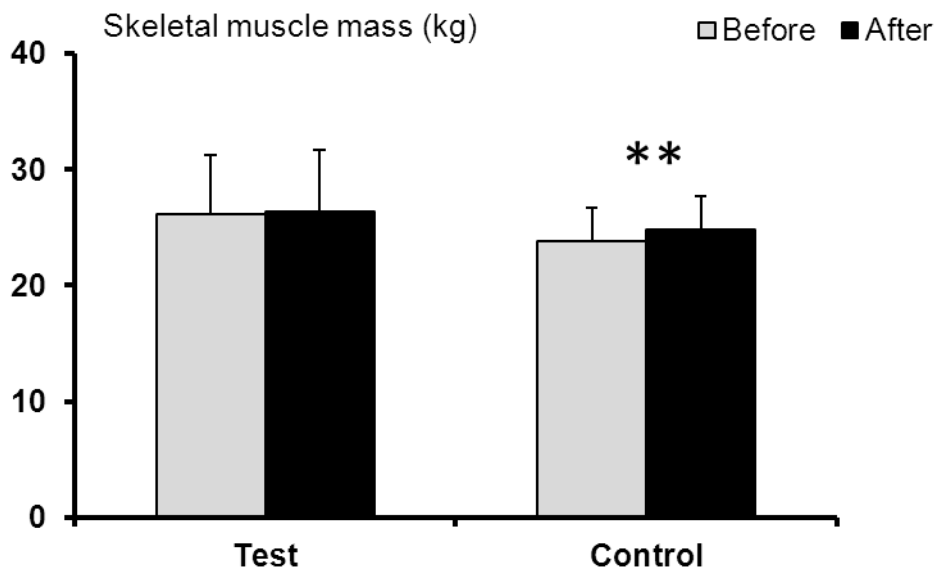

FIGURE 7. Changes in skeletal muscle mass before and after the 8-week training period in the test and control groups.

7.2 Endurance time, 30m sprint, flexibility, ball throwing and standing long jump

Endurance time, running until exhaustion, improved in the test group (n=25) from 13.4 ± 3.0 min to 14.9 ± 2.3 min (p < 0.001). The control group's (n=13) endurance time did not change (10.5 ± 3.4 min vs. 9.9 ± 3.9 min) (figure 8).
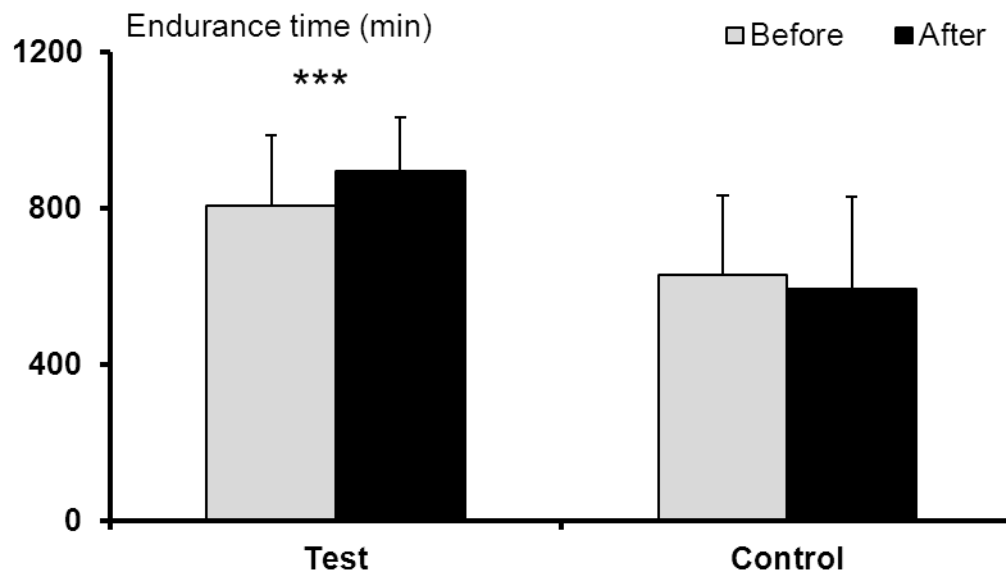

FIGURE 8. Changes in endurance time before and after the 8-week training period in the test and control groups.

30 meters sprint time did not change in the test group (5.1 ± 0.4s vs. 5.0 ± 0.4 s) neither in the control group (5.4 ± 0.4s) (figure 9).
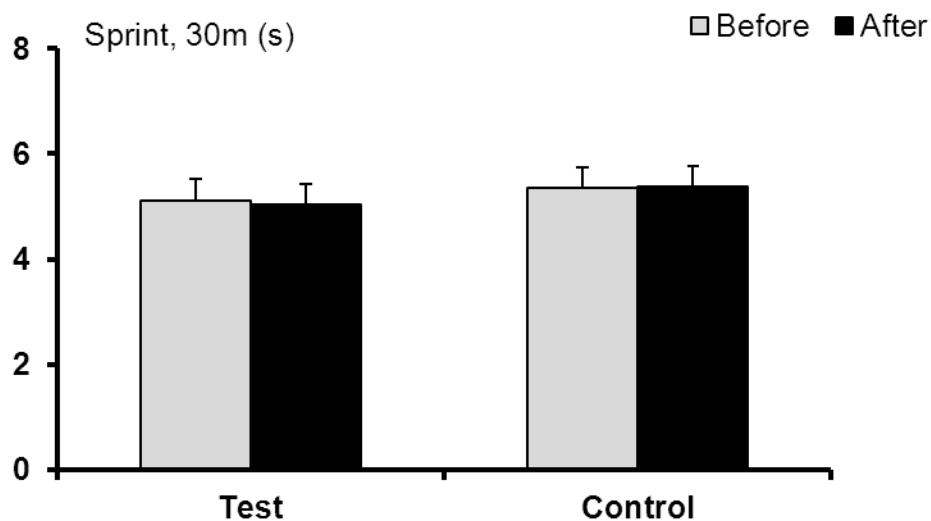

FIGURE 9. Changes 30 meters sprint time before and after the 8-week training period in the test and control groups.

Flexibility improved significantly in the test group, from 25.7 ± 7.9 cm to 27.2 ± 7.5 cm ($p<0.05$). There were no changes in the control group's flexibility (figure 10).
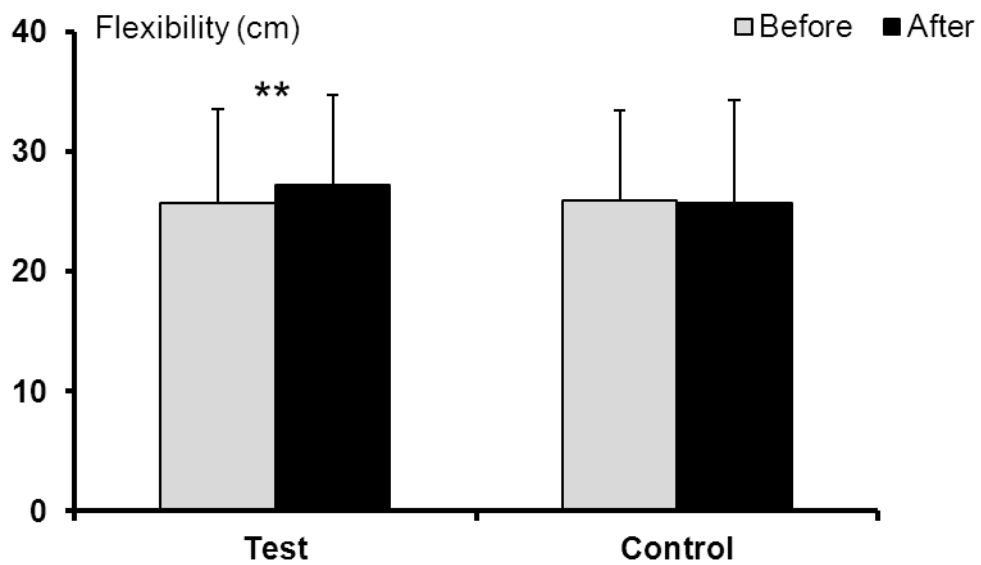

FIGURE 10. Changes in flexibility before and after the 8-week training period in the test and control groups.

Ball throwing. Ball throwing with 3 kg medicine ball improved in the test group from 5.1 ± 1.6 m to 5.4 ± 1.7 m ($p<0.01$). The control group's values did not change (4.6 ± 1.1m vs. 4.3 ± 0.9 m).
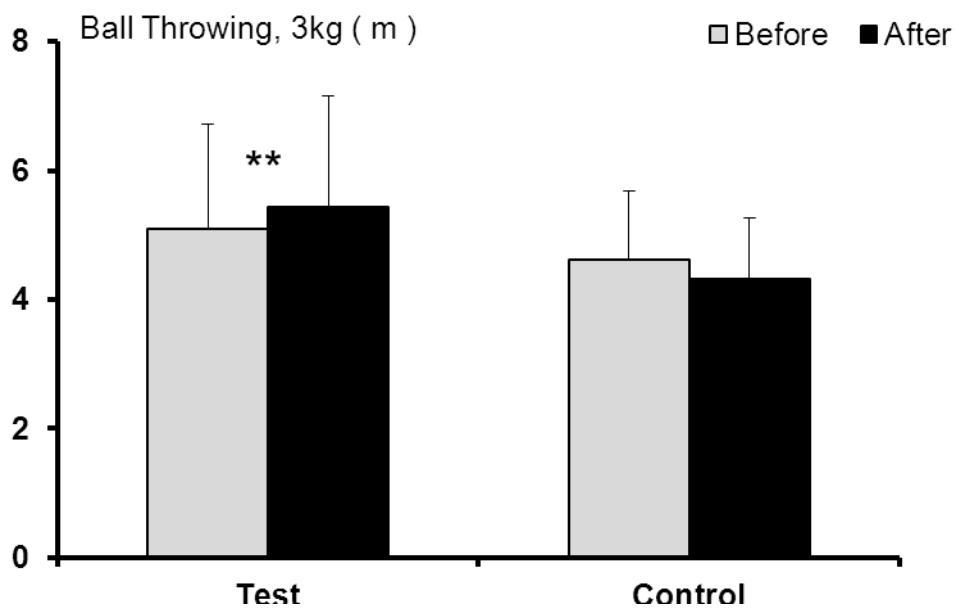

FIGURE 11. Changes in ball throwing before and after the 8-week training period in the test and control groups.

In standing long jump, no significant changes were observed. Results in the test group were from 1.8 ± 0.4 m to 1.9 ± 0.4 m (p<0.1) and in the control group from 1.7 ± 0.3 m to 1.6 ± 0.3 m.
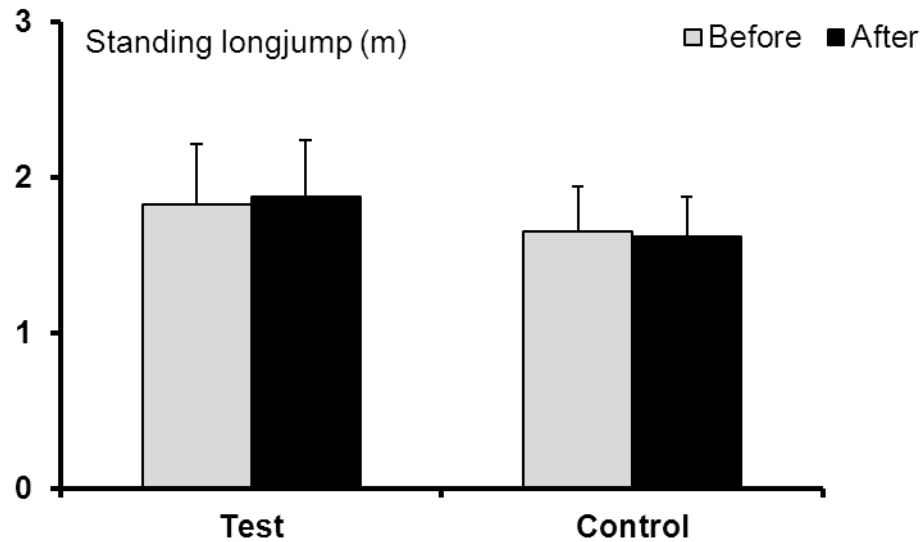

FIGURE 12. Changes in standing long jump results before and after the 8-week training period in the test and control groups.

7.3 Heart rate variability

During standing the test group's (n = 11) HRV variables before and after the training period were LF 6.2 ± 0.9 vs. LF 6.8 ± 0.9 (p = 0.285), HF 4.3 ± 1.4 vs. HF 5.0 ± 1.0 (p = 0.187). Changes were not significant. LF/HF decreased (p = 0.114), but the change was not significant: LF/HF 1.5 ± 0.4 vs. LF/HF 1.40 ± 0.23 (figure 13). In supine position, the test group's HRV variables did not change (n = 12): LF 6.9 ± 1.3 vs. LF 6.9 ± 0.7 (p = 0.685); HF 6.6 ± 1.3 vs. HF 7.2 ± 0.76 (p = 0.106); LF/HF 1.0 ± 0.1 vs. LF/HF2 1.0 ± 0.1 (p = 0.148) (figure 14).

Only four control group students' HRV measurements in standing position and three ones in supine position were applicable, and there were no significant changes in those.

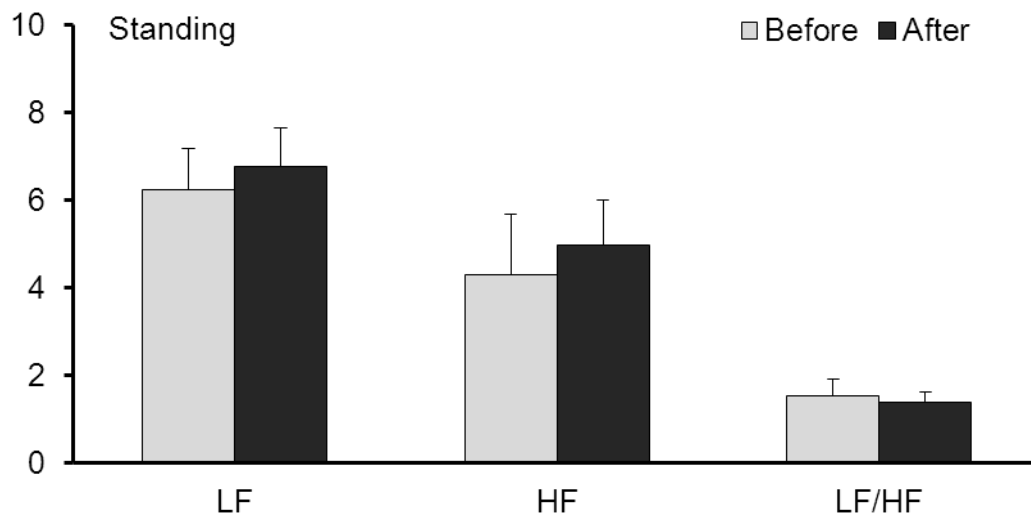FIGURE 13. The test group's HRV variables as measured in standing position before and after the 8-weeks training period.
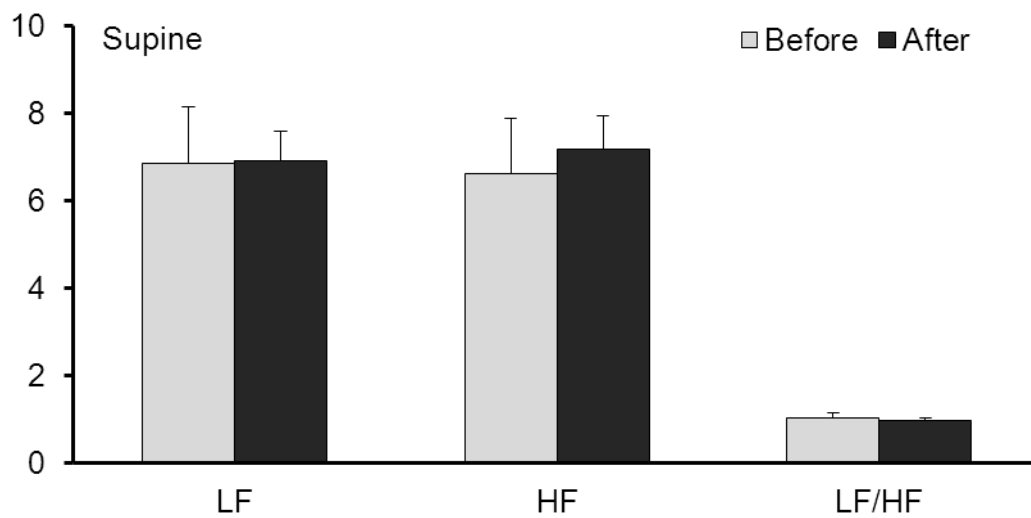

FIGURE 14. The test group's HRV variables as measured in supine position before and after the 8-weeks training period.

7.4 Associations between HRV and endurance variables

When test and control groups were combined no significant correlations were found between HRV and endurance variables.

8 DISCUSSION

Physical capacity and physical performance improved during the eight weeks physical training in the test group, but there were no improvements in physical capacity or physical performance in the control group. The high physical activity level of adolescents provides health benefits and it can also have a role in improving educational skills and well-being (Kantomaa 2010). Previous studies have shown that endurance training of prepubertal healthy children has a positive effect on aerobic potential, morphological and functional cardiac parameters (Bucheit et al. 2002).

Eight weeks physical training improved the aerobic capacity of the test group, as shown by the improvements in endurance time ($p<0.001$). Significant improvements in flexibility ($p<0.05$) and ball throwing ($p<0.01$) also improved overall physical performance. In the control group, respective performance variables decreased or stayed the same. The training period was beneficial to the test group students even though they were physically active already earlier. Their endurance capacity increased perhaps because new diverse forms of exercise were added to their already existing physical activities. The test group being physically active and the short training period could have been the reasons why their skeletal muscle mass did not however change.

The control group's SMM increased ($p<0.01$) and the fat% decreased ($p<0.01$). Greater overall physical activity level and related energy consumption, which normally happens to Finnish pupils during the spring season, may have led to the reduction of the fat% and to the increase in SMM in the control group. This increase in physical activity was not intense enough to improve the endurance capacity of the control group pupils.

No significant changes were observed in HRV in the test group. Standing LF/HF decreased, but the change was not significant. Before the training period standing LF/HF was 1.5 ± 0.4 and after 1.40 ± 0.23 ($p = 0.114$). The test group pupils were physically active before the eight weeks training. The test group results are in line with the studies of Henje Blom et al. (2009) and Gamelin et al. (2009). Henje Blom et al.

studied how lifestyle factors affect HRV in healthy adolescents who were 16 to 18 years old. HRV was registered for four minutes in sitting position and repeated after six months. They found a significant correlation ($p<0.05$) between self-reported physical activity and HRV, but there were no correlations to sleeping patterns, eating habits or smoking. There was a six months period between the two measurements and thus they concluded that longer duration regular physical activity enhances vagal influence on the cardiac rhythm. Gamelin et al. (2009) were studying the effects of 7 weeks high intermittent training on HRV in children at the ages of 9.6 ± 1.2 years. There was improvement in aerobic fitness, but they did not find any significant changes in HRV parameters. Their conclusion was that seven weeks training period was able to improve physical fitness, but seven weeks training period was not able to bring out any significant effects on HRV. In our study the training period was only eight weeks and there was a significant improvement in endurance capacity, but no changes in HRV parameters. We could thus think that the test group students' physical activity before the training had already had an effect on their HRV parameters and the short eight weeks intensive training period did not have any further effects on HRV.

In the present study HRV parameters did not change due to training and therefore correlations between the changes in HRV and other parameters were not reported. When calculating correlations between HRV (HF, LF and LF/HF) and endurance capacity no significant relation was found. This is in contrast with Hautala et al. (2003). In their study they found a significant correlation between the aerobic training response and HRV parameters in healthy sedentary subjects who were 23-52 years old. Finley et al. (1995) studied the effects of age to HRV. The parasympathetic activity of children older than 6 years seems to gradually decrease. Age dependant changes in HRV may be related to the maturing process of autonomic nervous system and also to the increase of the cardiac volume occurring with growth from infancy to adulthood.

We may thus conclude that factors such as the age of the test group pupils, the length of the training period and the physical activity of the test group pupils already before the physical training affected together so that no significant changes in HRV were observed. However, the change in HRV parameters, namely HF, were indicators of positive progress. In both standing and supine position HF increased, but not

significantly: standing HF 4.3 ± 1.4 vs. HF 5.0 ± 1.0 (p = 0.187), supine HF 6.6 ± 1.3 vs. HF 7.2 ± 0.76 (p = 0.106). The increase in HF is considered to be mainly due to vagal efferent activity thus showing an increase in parasympathetic activity (Task Force, 1996).

Several factors are known to affect the reliability of HRV results. Winsley et al. (2003) pointed the importance of tight control of external influences. In the present research that was not achieved at all times. For instance, extra noise was heard during some HRV measurements, some others had drunk caffeinated drink or eaten lunch prior to testing. Additionally some test group students had cycled or run preceding testing. Clear instructions, both on paper and in information meetings, had been given to participants regarding what to do and not to do before the HRV measurements. With adolescents it can be said that important information must be repeated several times for reliable compliance to be expected. Personal commitment to the research varied among pupils. Some participants had taken part in other research projects during that school year and, despite volunteering in this one, did not remain committed. The time for second measurements was at the end of the school year, when there are many exams. Some pupils were having an exam directly after the measurement thus having extra stress. Dishman et al. (1999) showed that there is a weak inverse relationship between emotional stress and vagal modulation of HRV.

The following factors could have affected the reliability and the results of the HRV parameters in this study: external influences did not stay the same; pupils did not follow the given advice; commitment among the pupils was weak; stress factors changed; the time of the year changed the physical activity level among all the pupils; the test group pupils were physically active already before the research and the length of the training period could have been too brief. The pupils were between ages 13 – 15 thus their maturing and growing processes in hormonal, nervous system and physical areas were at different stages.

Future studies are needed to show the relationship between increased physical activity level and autonomic cardiac function in adolescents. In future studies, the training period should be longer and, if possible, both the test and control group pupils should not be physically active before the study and the control group students should keep

the same physical activity level during the whole time of the study. The participants should also be well motivated. Outward circumstances during HRV measurements should be kept as standardized as possible throughout the study. All these requirements for reliable study are not easy to achieve with children, so extra motivational and rewarding means would be worth considering.

9 CONCLUSIONS

Eight weeks of instructed physical training improved physical performance and aerobic capacity of the secondary school pupils. Physical training is clearly beneficial as shown by many improved performance parameters and can be recommended to adolescents. Improvements in cardiac autonomic function after eight weeks physical training was not seen as clearly as it has been observed in adults (Hautala et al. 2003). The relationship between physical activity level and the autonomic nervous system functions was not proven, however longer-duration training periods may show a relationship.

In conclusion:

1) Eight weeks instructed physical training is beneficial for adolescents. Evidence of this is seen in better performance, especially in aerobic capacity.

2) There were no changes in HRV variables after eight weeks instructed physical training indicating that the stress level before and after the physical training remained the same.

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11 APPENDICES

11.1 Appendix 1, Approval and background information

Liikunta-aktiivisuuden yhteys autonomisen hermoston toimintaan ja fyysiseen suorituskykyyn yläasteen oppilailla

TIEDOTE TUTKITTAVILLE JA SUOSTUMUS TUTKIMUKSEEN OSALLISTUMISESTA

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Tutkimuksen taustatiedot

Tutkimus tehdään nelikantayhteistyönä. Tahot ovat: Oviedon yliopisto, Espanja, IES Mar del Sur de Taraguilla (Cadiz) –koulu Espanjasta, Jyväskylän yliopisto ja Jyväskylän kaupunki, jota edustaa Kuokkalan koulu. Suomessa tutkimuksen toteuttamiseen osallistuvat Jyväskylän yliopistolta, liikuntabiologian laitokselta vastuullisena tutkijana professori Vesa Linnamo ja professori Heikki Kyröläinen. Kuokkalan koululta rehtori Seppo Pulkkinen ja liikunnanopettajat Tuuli Matinsalo, Markku Rahikkala ja Jarmo Saikkonen. Tutkimuksen käytännön toteuttajana on Dr. Pablo Yagüe Ares ja tutkimusassistenttina Laura Fernandez Fernandez. Tutkimuksesta tehdään pro gradu työ Jyväskylän yliopiston liikuntabiologian laitokselle Liisa Kraaman toimesta. Tutkimus toteutetaan kevään 2009 aikana.

Tutkimusaineiston säilyttäminen

Tutkimuksen vastuullinen tutkija vastaa tutkimusaineiston turvallisesta säilyttämisestä siten, etteivät tiedot tutkimuksesta ja yksittäisistä tutkittavista joudu ulkopuolisten käsiin. Eettisen toimikunnan lausuntoa haettaessa on täytetty rekisteriseloste. Tutkimuksesta kerätty manuaalinen aineisto säilytetään liikuntabiologian laitoksen tiloissa ja ATK:lla oleva aineisto tutkijoiden omilla tietokoneilla ja varmuuskopioina muistitikuilla/CD-levyillä. Koehenkilöiden tietoja sisältävät ATK-aineistot arkistoidaan lukittuun kaappiin liikuntabiologian laitoksen tiloissa.

Tutkimuksen tarkoitus, tavoite ja merkitys

Koululaisten liikunta-aktiivisuuden on todettu vähentyneen viimeisten vuosikymmenten aikana. Säännöllinen liikunta ehkäisee ylipaino-ongelmia ja monia hengitys- ja verenkiertoelimistön sairauksia. Liikunnan puutteesta johtuvat ongelmat motorisessa suorituskyvyssä voivat puolestaan johtaa ongelmiin tasapainon hallinnassa ja aiheuttaa kaatumistapaturmia. Oikealla liikunnan ja levon tasapainolla saatetaan myös pystyä kontrolloimaan elimistön stressitilaa ja näin edesauttaa esim. oppimisvalmiuksia.

Tutkimuksen tavoitteena on vastata seuraaviin kysymyksiin:
1. Onko oppilaiden liikunta-aktiivisuudella yhteyttä sykevälivaihtelun avulla mitattuun autonomisen hermoston tilaan?
2. Onko oppilaiden liikunta-aktiivisuudella yhteyttä fyysiseen suorituskykyyn?
3. Voidaanko 8 viikon ohjatulla liikunnalla vaikuttaa autonomisen hermoston tilaan ja fyysiseen suorituskykyyn?
4. Miten suomalaisten ja espanjalaisten yläasteoppilaiden fyysiset ominaisuudet eroavat toisistaan

Menettelyt, joiden kohteeksi tutkittavat joutuvat

Pituus, paino, kehon koostumus ja sykevariaatio
Paino ja kehon koostumus mitataan bioimbedanssi-menetelmällä ja sykevariaatio sykemittarilla lepotilanteessa sekä seisomaan nousun jälkeen (ortostaattinen koe).

Aerobinen suorituskyky

Kestävyyskuntotesti (Légerin testi) (20 metrin monivaiheinen sukkulajuoksutesti) ja progressiivinen aerobinen testi, jossa juostaan salia ympäri ensin nopeudella 7 km/h, jota lisätään 0.20 km/h joka 30 sekunnin välein. Mitataan syke joka 5. sekunti, maksimisyke ja maksiminopeus.

Voimatestit

Vauhditon pituushyppy, roikkumistesti kädet koukussa 3 kg kuntopallon kanssa, staattinen- kevennys- ja pudotushyppy kontaktimatolla.

Nopeus

30 metrin nopeus testi, 10 x 5m sukkulajuoksu (Eurofit Battery).

Notkeus

Istualtaan kurkotustesti

Liikuntakäyttäytymiskysely
Kyselyllä selvitetään fyysistä aktiivisuutta oheisen liitteen mukaisesti.

Edellä mainitut testit ja kyselyt tehdään kaikille tutkimukseen osallistuville oppilaille (noin 100). Vastaavia mittauksia on jo tehty Espanjassa samanikäisille koululaisille. Näiden perusmittausten lisäksi osa oppilaista (noin 20) osallistuu 8 viikon ohjattuun harjoitteluun kolme kertaa viikossa tunnin kerrallaan. Tämä koeryhmä sekä kontrolliryhmä (noin 20) toistaa perusmittaukset toisen kerran 8 viikon jälkeen.

Harjoittelu

Kolmesti viikossa toteuttava harjoittelu koostuu seuraavista osa-alueista:

Lämmittely: 10 min

Kuntopiiri: Perusharjoitteita tärkeimmille lihasryhmille noin 20min per kerta.

Aerobinen harjoittelu: Hölkkää ja erilaisia pallopelejä (salibandy, sisäjalkapallo) 20 min yksilöllisen ohjelman mukaan siten, että teho on noin 70 – 75% kestävyystestissä saavutetusta maksimisykkeestä. Aerobisen harjoittelun kesto nostetaan 30 minuuttiin ja syketasoa nostetaan 5% viikossa ensimmäisen 4 viikon jälkeen.

Rentoutuminen ja venyttely (noin 10min) jokaisen harjoituskerran lopussa.

Tutkimuksen hyödyt ja haitat tutkittaville

Tutkittavat saavat tietoa kehonkoostumuksestaan sekä fyysisistä ominaisuuksistaan. Oppilaat pääsevät kokemaan kansainvälistä ilmapiiriä ja harjoittamaan kielitaitoaan, kun mittausten käytännön toteuttamisesta

vastaavat espanjalaiset tutkijat. Harjoitteluryhmällä saa ohjattua liikuntaa 8 viikon ajan.

Tutkimukseen liittyvät riskit ovat pieniä. Käytetyt mittausmenetelmät ovat standardikäytössä ympäri maailmaa Kaikki mittaukset ja ohjattu harjoittelu toteutetaan asiantuntevien liikunta-alan tutkijoiden toimesta. Lisäksi koulun terveydenhoitaja on käytettävissä tutkittavien terveystilaa koskevissa asioissa. Pieni tapaturmariski toki on olemassa, kuten tavallisellakin liikuntatunnilla. Tutkijat ja mittaajat ovat valmiita selvittämään yksityiskohtaisemmin mittauksia ja niihin liittyviä riskejä ja niistä saatavaa hyötyä. Suorituskykytestit ovat osin maksimaalisia ja niiden seurauksena normaalia kuormitukseen liittyvää lihaskipua 2-3 päivää testien jälkeen. Harjoittelu voi aiheuttaa väsymystä ja mahdollisesti muita kiputuntemuksia.

Miten ja mihin tutkimustuloksia aiotaan käyttää

Tutkimustuloksia hyödynnetään Liikuntatieteellisessä tiedekunnassa tehtäviin opinnäytetöihin ja kansallisiin ja kansainvälisiin tieteellisiin julkaisuihin. Tuloksia esitellään kansallisissa ja kansainvälisissä tieteellisissä kongresseissa.

Tutkittavien oikeudet

Osallistuminen tutkimukseen on täysin vapaaehtoista. Tutkittavilla on tutkimuksen aikana oikeus kieltäytyä mittauksista ja keskeyttää testit ilman, että siitä aiheutuu mitään seuraamuksia. Tutkimuksen järjestelyt ja tulosten raportointi ovat luottamuksellisia. Tutkimuksesta saatavat tiedot tulevat ainoastaan tutkittavan ja tutkijaryhmän käyttöön ja tulokset julkaistaan tutkimusraporteissa siten, ettei yksittäistä tutkittavaa voi tunnistaa. Tutkittavilla on oikeus saada lisätietoa tutkimuksesta tutkijaryhmän jäseniltä missä vaiheessa tahansa.

Vakuutukset

Kaikki tutkimukset tehdään koulun tiloissa kouluaikana, joten tutkittavat ovat vakuutettuja normaalin koululiikuntakäytännön mukaisesti.

Tutkittavan suostumus tutkimukseen osallistumisesta

Tutkittavan nimi _____
syntymäaika: _____

Yhteystiedot

_____
_____

Alaikäistä lastani on pyydetty osallistumaan tutkimukseen **" Liikunta-aktiivisuuden yhteys autonomisen hermoston toimintaan ja fyysiseen suorituskykyyn yläasteen oppilailla"**. Vakuutan, että luettuani koehenkilötiedotteen ja saatuani haluamani lisäinformaation suostun lapseni osallistuvan tutkimukseen vapaaehtoisesti ja ilman painostusta. Minulla on ollut riittävästi aikaa harkita lapseni osallistumista. Tiedän voivani milloin tahansa peruuttaa suostumukseni ja siten keskeyttää lapseni osallistumisen tutkimukseen. Lapseni ei osallistu mittauksiin flunssaisena, kuumeisena, toipilaana tai muuten huonovointivointisena. Ymmärrän tutkimuksen hyödyt ja haitat. Mikäli haittavaikutuksia ilmenee, lupaan viipymättä ilmoittaa niistä tutkimushenkilökunnalle.

Oppilas_____ (nimi ja luokka)

saa (   ) ei saa osallistua (   ) Liikunta-aktiivisuuden yhteys autonomisen hermoston toimintaan ja motoriseen suorituskykyyn yläasteen oppilailla.

_____ ____/____/2009
Oppilaan huoltajan allekirjoitus

_____ ____/____/2009
Tutkijan allekirjoitus

11.2 Appendix 2, Feedback

Liikunta-aktiivisuuden yhteys autonomisen hermoston toimintaan ja fyysiseen suorituskykyyn yläasteen oppilailla –tutkimus Kuokkalan yläasteen oppilaille keväällä 2009

Palaute tutkimukseen osallistuneille

Kuntotestit

Voit verrata omia tuloksiasi koulusi samanikäisten oppilaiden keskiarvotuloksiin (average). Seuraavaksi lisää tietoa kunkin testin merkityksestä.

Kurkotustesti istualtaan (Flex)
Tätä testiä käytetään yleisesti notkeuden (Flexibility) mittaamiseen. Erityisesti testillä mitataan alaselän ja reiden takaosan lihasten joustavuutta (elastic). Tämä testi on tärkeä, sillä näiden alueiden kireys tulee esille lannealueen lordoosissa (notkoselkä), lantion eteenkallistumassa sekä alaselän kivussa.

Pallonheitto eteenpäin (3kg kuntopallo) (Strenght, Medicine Ball 3kg)
Tällä testillä mitataan ylävartalon voimaa ja voimantuottoominaisuuksia. Nämä kaksi tekijää ovat tärkeitä ylävartalon voimaa vaativissa urheilulajeissa kuten soutu, tennis ja keihäänheitto.

Vauhditon pituushyppy (Long jump)

Vauhditon pituushyppy on yleinen ja helppo tapa mitata jalan lihasten voimantuottoa. Vauhditon pituushyppy on myös aikanaan ollut olympialaji.

Hyppy ylöspäin - vertikaalihyppy

Hyppy ylöspäin on yksi kaikkein räjähtävimmistä fyysisistä liikkeistä, mitä urheilussa tulee esille. Useissa urheilulajeissa on urheilijalla sitä paremmat menestymisen mahdollisuudet, mitä korkeammalle hän kykenee hyppäämään. Koripallo ja lentopallo ovat kaksi kaikkein tunnetuinta urheilulajia, joissa tämä on selkeästi nähtävissä. Urheilijan hyppykyky kertoo myös yleisesti hänen kyvyistään, koska hyppäyskyvyn ja lyhyiden matkojen juoksunopeuden kehityksen välillä on selvä suhde.

Vertikaalihypylle on useita testausmuotoja: staattinen hyppy (kyykkyhyppy) (squat jump, SJ) testaa räjähtävää voimantuottoa; kevennyshyppy pudotushyppy (counter movement jump, CMJ) testaavat elastista räjähtävän voiman tuottoa; pudotushyppy (drop jump) 40 cm korkeudelta kertoo nopeusvoimasta.

10 x 5 metrin sukkulajuoksu

Tämä testi mittaa nopeutta ja ketteryyttä (agility). Koko 50 metrin matkaan kulunut aika mitattiin.

Kestävyystesti (Endurance test) ja 20 metrin monivaiheinen sukkulajuoksutesti (Multistage Fitness Test, MSFT)

Näitä testejä käytetään yleisesti maksimaalisen aerobisen juoksukunnon testaamisessa. Testit tunnetaan myös nimillä 20 metrin sukkulajuoksutesti ja piiptesti (Beep test). Testissä mitataan suoritusaika, loppunopeus (V = velocity, km/h) ja sydämen maksimisyke (Heart rate max = HR max, beats / min = lyöntiä/min). 20 metrin monivaiheisen kuntotestin maksimiajan avulla voidaan laskea myös maksimaalinen hapenottokyky, VO2max (l/kg/min).

30 metrin nopeustesti

Pikajuoksu- ja nopeustestejä voidaan suorittaa eri pituisilla matkoilla riippuen siitä, mitä halutaan testata ja mikä on testin merkitys tutkittavalle urheilulajille. Me testasimme nopeutta 30 metrin matkalla mitaten nopeuden 10 metrin ja 30 metrin kohdalla.

Kehonkoostumus

BMI (Body Mass Index), painoindeksi, lasketaan painon ja pituuden avulla jakamalla paino (kg) pituuden (m) neliöllä (paino : $pituus^2$). Painoindeksiin vaikuttavat rasvakudoksen ja lihaskudoksen määrät. Aikuisilla painoindeksin normaali viitealue on 19-25 kg / m^2. 13 – 15 – vuotiailla pojilla normaalin painoindeksin yläraja on 23 pituudesta riippuen. Samanikäisillä tytöillä normaalin painoindeksin yläraja on 24.

Rasvan prosentuaalinen osuus kehon massasta ja kehon rasvan määrä kilogrammoina kertovat rasvakudoksen määrästä. Pituus, paino ja lihasmassan määrä vaikuttavat näiden viitearvoihin.

Rasvan prosentuaalisen osuuden normaaliarvot ovat 17 -28 % 13 – 15 –vuotiailla tytöillä. Samanikäisillä pojilla rasvan prosentuaalisen osuuden viitearvot ovat 10 – 20%.

Lihasmassan määrä kiloina (SMM, skeletal muscle mass) kertoo luurankolihasten, liikuntalihasten määrästä. Sen normaaliarvot 13 – 15 –vuotiailla pojilla vaihtelevat suuresti pituudesta, painosta ja kehon muusta rakenteesta johtuen.

Sydämen sykevälivaihtelu

Sydämen sykevälivaihtelua mitattiin levossa, ylösnoustessa ja seisaaltaan ollen. Sykevälimittauksen avulla saadaan tietoa autonomisen hermoston parasympaattisen puolen toiminnasta. Aikuisilla tehdyissä mittauksissa on todettu liikunnan lisäävän positiivista sykevälivaihtelua, joka puolestaa kertoo liikunnan stressiä vähentävästä vaikutuksesta.

Sykevälivaihtelu mittausten analysointi on vielä kesken, joten siitä emme voi antaa henkilökohtaista palautetta.

Kysymyksiä

Jos sinulla on kysyttävää testituloksistasi, voit ottaa yhteyttä omaan liikunnanopettajaasi tai tutkimusprojektin johtajaan professori Vesa Linnamoon, Jyväskylän Yliopiston liikuntabiologian laitoksella.

Kiitos

Kiitos jokaiselle tutkimukseen osallistuneelle!