UNIVERSITY OF TARTU

Institute of Sports Sciences and Physiotherapy

Krete Junson

Relative energy deficiency in sport

Suhteline energia defitsiit spordis

Bachelor thesis

Faculty of Exercise and Sport Sciences

Supervisor:

Lecturer, M. Mooses (PhD)

Tartu, 2018

TABLE OF CONTENTS

ABBREVIATIONS

BMI - body mass index

BMD - bone mineral density

DE - disordered eating

DXA - dual-energy X-ray absorptiometry

EA - energy availability

EB - energy balance

ED - eating disorder

EDNOS - eating disorder not otherwise specified

EEE - exercise energy expenditure

EI - energy intake

FFM -fat free mass

FSH - follicle-stimulating hormone

IGF -1 - insulin-like growth factor I

IOC - International Olympic Committee

LEA - low energy availability

LH - luteinizing hormone

RED-s - relative energy deficiency in sports

ST - standard deviation

Triad - the female athlete triad

TT3 - triiodothyronine

INTRODUCTION

The study focuses on a difficulty that affects athletes, their nutrition, health and general sports performance. High volume trainings among amateur sportsmen and top athletes leads the human organism into extreme state which could be both positive or negative. High-level sport is healthy only in case of correct training principles has been followed. Trainings must be monitored and conditioned individually while taking enough rest and ensuring sufficient nutritional strategies. It is important to take into consideration the peculiarities of different sports when athlete pursues towards maximum performance.

Relative energy deficiency in sports (RED-s) is a condition that occurs among athletes with long-term low energy availability (LEA). It emerges when dietary energy intake is insufficient or when energy expenditure is extremely high e.g. endurance sports athlete's. RED-s is derived from more known female athlete triad (Triad), which is a combination of disordered eating/eating disorders (DE/ED), irregular menstrual cycles and low bone mineral density (BMD) (Mountjoy *et al*., 2014; Mountjoy *et al.,* 2015, Sundgot-Borgen *et al*., 2013). These syndromes were found in women whose energy intake (EI) was inadequate to assure body's normal physiological functioning and later comparable symptoms have been found among men as well (Mountjoy *et al*., 2014; Mountjoy *et al.,* 2015).

Different from Triad, in addition to menstrual function, RED-s may affect energy availability (EA) and bone health and many other physiological functions. During recent years, studies have shown that the symptoms of the Triad can also be found among men so this increased the need for comprehensive term such as relative energy deficiency in sport (Marcason, 2016; Mountjoy *et al.*, 2014). As it is said previously RED-s may cause distinct health problems and therefore it is important to emphasize this problem.

The aim of the present thesis is to give an overview about Triad and RED-s conditions in relation to human performance. It is important for coaches, nutritionist and athletes themselves to increase the awareness of this conditions and to be familiar with how to monitor athletes to prevent the occurrence of serious health consequensces (Mountjoy *et al.,* 2014).

Keywords: athletes, nutrition, energy availability, female athlete triad, eating disorder, RED-s.

1. FEMALE ATHLETE TRIAD

The female athlete triad (Triad) was firstly described in 1992, when the three components - disordered eating, amenorrhea and osteoporosis - were sighted among women who take part in activities that accentuate a lean physique (Yeager *et al.*, 1993; Nattiv *et al.*, 2007). The relationship between EA, menstrual function and bone mineral density (BMD) may assure perfectly healthy organism but in insufficient correlation may lead to unhealthy manifestations (Nattiv *et al.*, 2007; De Souza *et al.*, 2014; 2017). The Triad affects women who are physically very active or who compete in sports which lead to extremely reduced body fat. Leanness caused by LEA (Manore *et al.*, 2007) can be found in patients with or without disordered eating (DE) (Melin *et al.*, 2014) . In afflicted women only one component presence is sufficient for diagnosing the Triad and any of the constituents negative progressions may lead to further health risks (Nattiv *et al.*, 2007, De Souza *et al.*, 2014, 2017).

Energy availability (EA), menstrual status and bone health interrelationship determine the presence of the Triad, even with one distinct symptom (De Souza *et al.*, 2014). Bases for the interdependence comes from energy availability associated with menstrual function and in turn EA and menstrual status which directly influences bone health (Drinkwater *et al.*, 1986; Mountjoy *et al.*, 2014). Therefore, healthy organism is assured by optimal energy availability, eumenorrhea and optimal bone health.

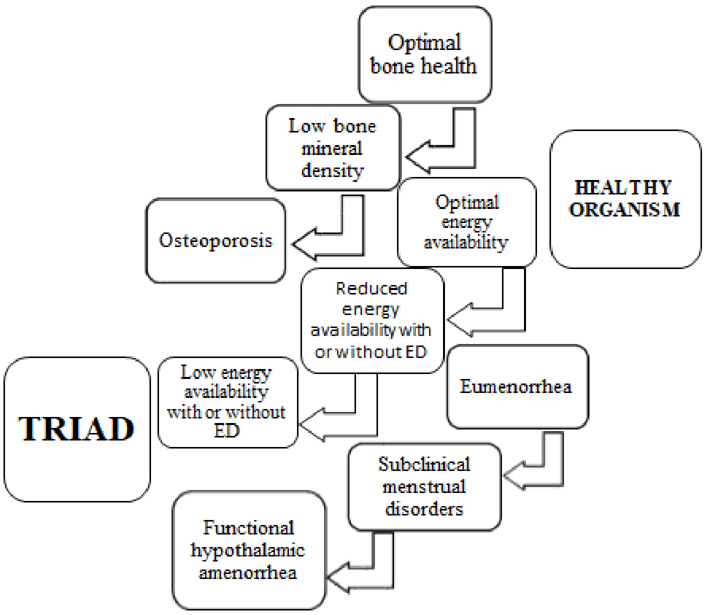


Figure 1. Triad severeness ranges from optimal health to subclinical conditions until sever form of Triad. All of th the aspects of the Triad influence one another (adapted from Nattiv et al., 2007).

On the contrary, insufficient energy intake (with or without ED) leads to LEA (Loucks 2004), infreaquent menstrual function evolves into funtional hypothalamic amenorrhea (Wade *et al.,* 1996) and low bone mineral density may cause osteoporosis (Ihle & Loucks 2004). Triad severeness ranges between the circumstances of the components (Figure 1).

The fundamental constituent of the Triad is energy deficiency coming from insufficient or low energy availability and to accentuate energy balance (EB) is neither a considerable notion (Loucks *et al.,* 2011). According to Loucks *et al.* (2011) energy availability is defined as the amount of ‘unused’ dietary energy remaining for all other metabolic processes after the energy cost of exercise training is subtracted from the daily energy intake. Therefore, EA assures that our body’s physiological system functions normally. If energy availability occurs to be too low in the long-term a list of physiological functions will be affected negatively (Loucks 2004). In evidence to this corporal peculiarity the International Olympic Committee (IOC) Consensus group announced that the female athlete triad is not a triad of three entities of EA, menstrual function and bone health, but rather a syndrome resulting from relative energy deficiency that affects many aspects of physiological function including metabolic rate, menstrual function, bone health, immunity, protein synthesis, cardiovascular and psychological health (Mountjoy *et al.,* 2014).

Comparable symptoms with the Triad coming from relative energy deficiency are also found on men (Mountjoy *et al.,* 2014; Tenforde *et al.,* 2017). Consequently, the Triad needed to be modified into a broader term, which includes both men and women and their condition affected by long-term LEA (Mountjoy *et al*., 2014). In addition to the Triad the sports community is now also familiar with relative energy deficiency in sport (RED-s), which describes accurately the clinical syndrome affecting active male and female athletes specially in endurance events (ie. distance running, cycling) and events where body weigh, more precisely leanness, is considered to be performance discriminator (ie. aesthetic sports events, gymnastics, figure skating etc) (Marcason 2016, Mountjoy *et al.,* 2014; Mountjoy *et al.,* 2015).

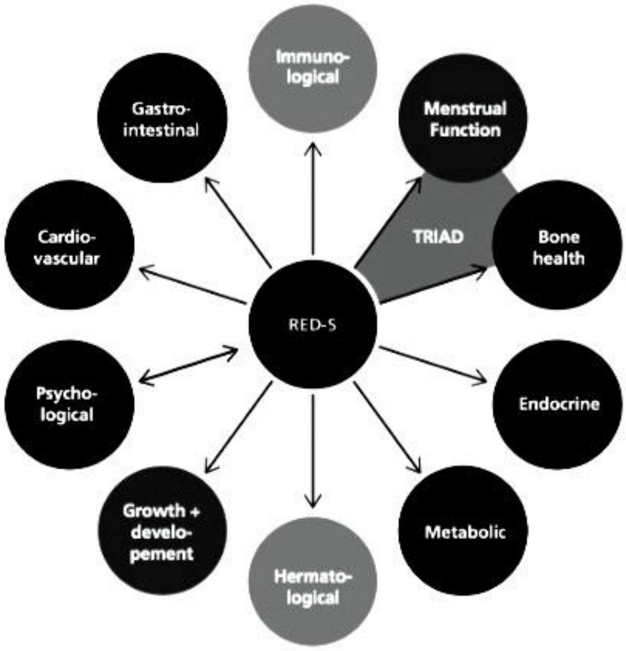
2. RELATIVE ENERGY DEFICIENCY

The term relative energy deficiency in sport was firstly described in the IOC consensus statement (Mountjoy *et al.*, 2014) which defines RED-s as it refers to impaired physiological function including, but not limited to, metabolic rate, menstrual function, bone health, immunity, protein synthesis, cardiovascular health caused by relative energy deficiency. As it is said previously, the syndrome of RED-s (or Triad) can occur single-handedly or in conjunction and in both men and women. Deficiency in energy intake (EI) and/or excessive energy expenditure results in low-energy condition and that is the underlying cause of RED-s (Mountjoy *et al.,* 2014; Statuta et *al.*, 2017). RED-s expresses in decreased performance and developing morbidity (Loucks *et al*., 2004). Sufficient energy intake for securing optimal health is evaluated as energy availability, since remaining energy balance may not correspond to athletes wish to modify their body for better performance (Loucks *et al.*, 2011).

According to Loucks (2004) energy intake minus the energy expended in exercise (EEE) relative to fat-free mass (FFM) equals energy availability (EA). As EA is like and input to the body's physiological systems, a decline in EI and/or an increase in EEE, causes adaptions in physiological functions such as disruption of an array of hormones and lower metabolic rate (Loucks 2004).

Low EA and Triad has been associated with only women for a very long time but in recent years the studies have documentations about LEA occurring in male athletes also (Sundgot-Borgen *et al.*, 2013). RED-s and LEA prevalently appear among men and female athletes who compete in weight-sensitive sports: 1) gravitational sports, in which high body weight restricts performance because moving the body against gravity is an essential part of these sports (long-distance running, cross-country skiing, road and mountain bike cycling, ski jumping and jumping in athletics) 2) weight-class sports, including combat sports (wrestling, judo, boxing, taekwondo, weight-lifting, lightweight rowing) 3) aesthetically judged sports (rhythmic and artistic gymnastics, figure skating, diving, synchronised swimming) (Mountjoy *et al.*, 2014; Sundgot-Borgen *et al.*, 2013). Among these sports athletes' performance roughly depends on their weight and appearance.

The fundamental difference between the Triad and RED-s is that RED-s also affects men and the symptoms do not include only three components (LEA, amenorrhea and osteoporosis), but disturbance of variety of physiological functions' (Mountjoy *et al.*, 2014). Health areas affected with RED-s are menstrual function, bone health, endocrine, metabolic, hematologic, growth, development, psychological, cardiovascular, gastrointestinal and immunologic function (Kroshus et al., 2018; Mountjoy *et al.,* 2014) (Figure 2).



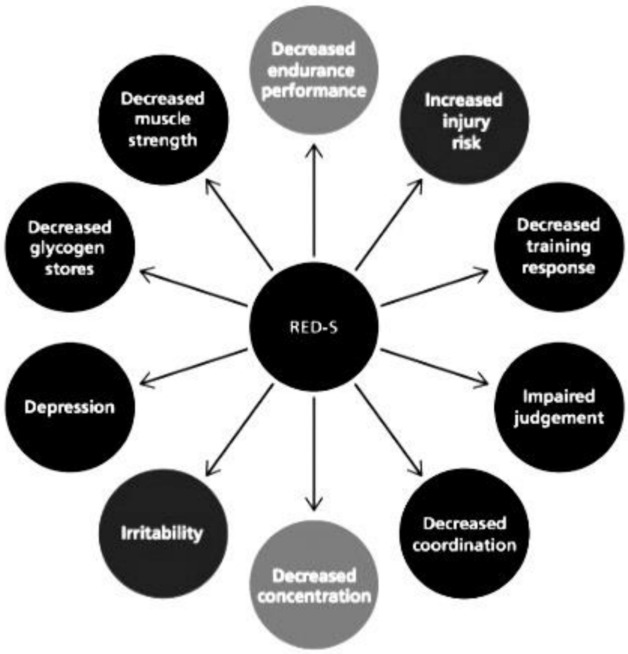


Figure 2. Health aspects that RED-s affects are pictured in the upper figure and performance aspects in the lower figure (adapted from Mountjoy *et al.,* 2014).

Same number of dysfunctions influence performance such as decreased endurance, increased injury risk, decreased training response, impaired judgment, decreased coordination, decreased concentration, irritability, depression, decreased glycogen stores and decreased muscle strength (Kroshus *et al.*, 2018; Mountjoy *et al.,* 2014) (Figure 2).

3. RED-S COMPONENTS:

3.1. Energy availability

RED-s is deficiency in energy intake, which results in LEA and brings along a decrease in body functions involved in optimal health and performance (Mountjoy *et al.*, 2014). When it comes to athletic training, focusing on energy balance with athletes' diet is not enough to achieve performance goals (Loucks *et al.,* 2011). The term EA plays a huge roll in keeping one's organism healthy and maintaining the ability to evolve efficiently. The concept of EA lies in understanding that dietary energy is expended in several fundamental physiological processes like cellular maintenance, thermoregulation, growth, reproduction, immunity and locomotion (Wade & Jones, 2004). What is more, Loucks *et al*. (2011) defines EA as dietary energy intake minus exercise energy expenditure (Equation 1)

$$EA = EI - EEE$$

Where EI is energy intake and EEE is exercise energy expenditure. All the energy left after EEE is necessary for physiological functions which means living and training with LEA is degenerative in the long-term. Loucks and her coauthors (2011) stressed that EA is an input to the body's physiological systems (Loucks *et al.,* 2011).

Papageorgiou *et al.* (2017) study about effects of reduced EA brings out why and how EA differs from energy balance. To start with, energy balance (EB) is calculated using total energy expenditure (TEE), whereas EA is defined with exercise energy expenditure (EEE), which is adjusted for muscle mass (Papageorgiuou *et al.*, 2017). If EA is considered as an input to the body's physiological systems then EB is more as an output from physiological systems since it does not contain reliable information about energy requirements (Loucks *et al.*, 2011). In addition, it is believed that energy balance will ensure the normal function of our organism, but increased EEE may actually depress bodily functions, so even with normal energy balance one might undergo LEA (Loucks *et al.,* 2011; Papageorgiou *et al.,* 2017). Taking account these differences between energy balance and energy availability, the concept of EA is more adequate to describe energy deficiency effects in athletes.

It has been determined that LEA implicates reproductive and skeletal health (Melin *et al.,* 2014; Nattiv et al., 2007; Slater *et al.,* 2017). The unit of energy availability is estimated in kcal per kg of fat free mass per day $(\text{kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1})$. Energy balanced healthy young adults EA should equal with 45 $\text{kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1}$ while lower than 30 $\text{kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1}$ implicates negative effects, such as inducing amenorrhea and impairing bone health by removing oestrogen's restraint on bone resorption (Hilton & Loucks 2000;

Loucks 2004, Papageorgiou *et al.,* 2017). What is more, muscle protein synthesis is reduced even at EA of 30 $\mathrm{kcal} \cdot \mathrm{kg\ FFM}^{-1} \cdot \mathrm{day}^{-1}$ (Mounjtoy *et al.*, 2014).

Studies about lowered EA (20-30 $\mathrm{kcal} \cdot \mathrm{kg\ FFM}^{-1} \cdot \mathrm{day}^{-1}$and 10-15 $\mathrm{kcal} \cdot \mathrm{kg\ FFM}^{-1} \cdot \mathrm{day}^{-1}$) have shown suppression of bone formation but significantly women show higher dependence on EA than men (Ihle & Loukcs 2004; Papageorgiou *et al*., 2017). Then again, these findings question RED-s occurrence and effect on men.

We cannot control how our body uses the fuel we got, when dietary intake is extenuated or when considerable amount of our available energy is diverted, our organism suspends the use of metabolic fuel in favour to proceed survival (Wade *et al.,* 1996). LEA appearance slows down physiological mechanisms by reducing the amount of energy used for cellular maintenance, tissue turnover, thermoregulation, growth, reproductive development and function (Loucks 2004, Wade *et al.,* 1996). For example, hormones which are promoting bone formation are being suppressed remotely because of the lack of energy (Nattiv *et al.,* 2007) and unfavourable lipid profiles and endothelial dysfunction caused by LEA increases cardiovascular risk (Mountjoy *et al.,* 2014). Taking into account these deductions, any kind of energy deficiency whether among athletes or nonactive person should be considered and monitored carefully.

There are different contingencies how EA is being reduced and they could be related to eating disorders (ED). LEA occurs if training volume is being enhanced and EEE increased and/or EI is reduced (Loucks 2004, Mountjoy *et al.,* 2014). Furthermore, reduced EI is often accompanied with disordered eating (DE) and remarkably eating disorders (ED) among athletes are somewhat surprisingly frequent problem in the world of sports (Johnson *et al.,* 1999). DE among athletes varies from restrictive eating and unhealthy dieting to abnormal eating behaviours and finally might evolve into ED (Sundgot-Borgen & Torsveit 2010). Thompson *et al.* (2017) defines ED as a pathological disturbance in eating that include acute misperceptions and concerns about body shape and weight (Thompson *et al.,* 2017). Abnormal eating behaviours such as fasting, binge-eating, purging or use of diet pills, laxatives diuretics and enemas are often practiced for achieving smaller body weight or leanness (Johnson *et al*., 1999, Nattiv *et al.,* 2007, Thompson *et al.,* 2017).

In physiological point of view, it is difficult to follow nutritional essentials to assure necessary nutrient and energy requirements. There is no strong biological imperative which betoken athlete to match ones EI and activity-induced energy expenditure (Loucks 2004). On the contrary, Loucks (2004) brings out studies which have shown that exercising does not increase hunger not after the training nor the next day while food intake was *ad libitum*. Experiment where the same amount of energy deficiency was produced by EEE and food deprivation, hungriness occurred only with food deprivation (Hupert *et al.,* 1998). Also, *ad libitum* macronutrient intake does not vary in case of changes in glycogen stores, carbohydrates and fat oxidation. Therefore, human organism does not function automatically when energy expenditure surpasses EI and athletes cannot rely on their appetite to maintain energy balance or specific macronutrient requirements (Loucks, 2004).

3.2. Eating disorders and disordered eating

Dieting can be divided into three states starting with healthy dieting (modest caloric intake reduction for achieving slow and steady weight loss), harmful dieting and disordered eating which includes abnormal eating behaviours (skipping meals, diet pills, over- and binge-eating, purging etc.) (Nattiv *et al*., 2007). Mismatching between energy intake and output should be carefully considered due to its abundant negative repercussion. Low body weight and lean physique are important performance determinants in some sports (e.g., endurance sports, weight-class sports, gravitational sports) but likely the actions towards low body weight and leanness incur abnormal eating behaviour among athletes (Fortes *et al*., 2014; Montjoy *et al.,* 2014; Nattiv *et al.,* 2007). Sundgot-Borgen and Torstveit (2010) have claimed that restrictive dieting is an important risk factor for DE and ED. Eating disorders prevalence in elite athletes is increasing as many athletes adopt behaviour that is typical of patients diagnosed with eating disorders (Sundgot-Borgen & Torstveit 2010; Thompson *et al.,* 2017; Yeager *et al.,* 1993). Restricting the intake of food for long period of time or self-inducing vomiting, using laxatives/diuretic drugs in purpose of losing body weight, strenuous extreme physical exercises are just few of the known disordered eating behaviours (Fortes *et al.,* 2014).

Mountjoy *et al.* (2014) in the IOC consensus statement pointed out that the DE continuum starts with appropriate eating and exercise behaviours, including healthy dieting and the occasional use of more extreme weight loss methods such as short-term restrictive diets with consuming less than 30 $\mathrm{kcal \cdot kg\ FFM^{-1} \cdot day^{-1}}$ (Mountjoy *et al*., 2014; Sundgot-Borgen 2010). In the worst case scenario athletes merge into more clearly disordered and unhealthy, even harmful eating which increases and develops into ED (Currie & Crosland 2009). Most common ED are anorexia nervosa and bulimia nervosa and the typical clinical diagnosis consists of critically low body weight, weight loss medications clinical abuse, obsession about their physical appearance or distorted perception of their body size (Fortes *et al.,* 2014). When it comes to bulimia, binge eating (episodes of uncontrollable eating) followed by vomiting is also included in the diagnosis. Patient whose symptoms do not meet these criteria gets diagnosed with eating disorder not otherwise specified (EDNOS) (Sundgot-Borgen & Torstveit 2010).

Studies have showed that the number of ED sufferers is higher among athletes than in general population since athletes, who seek for ideal body composition (low body weight, lean physique) practice unhealthy eating behaviours more frequently compared to non-athletes (Fortes *et al.,* 2014; Johnson *et al.,* 1999; Thompson *et al.,* 2017). Though, sporting facilities are full of opportunities to optimise performance, monitor trainings and health, it is suggested that athletes feel pressure to improve their body weight at every cost. Furthermore, competitive environment enlarges the risk for the development of ED (Fortes *et al.,* 2014).

Other reasons that contribute to the occurrence of ED are the perception of appearance of the specific sport and the belief about performance improvement with specific body type (Sungot-Borgen & Torstveit, 2010). Personality factors, relationships between athletes, frequent weight fluctuation, early start of sport-specific training, overtraining and injuries are also important risk factors for abnormal eating behaviour (Nattiv *et al.,* 2007). Sundgot-Borgen and Torstveit (2010) also emphazise that coaches and their behaviour affects athletes and may facilitate or on the other hand preclude unhealthy eating habits.

Currie and Crosland (2009) proposed guidelines about nutrition in elite sport, which include the purposes of athletes eating and diet, guidelines for preventing eating disorders and over-all eating problems in high performance sports environment. They bring out that the diet of an athlete should correspond to maintaining health and, more importantly, athletes diet should ensure proper nutrition for performance. This means that nutrition must assure adaptions to training, aid recovery from training and prepare athlete for competition. Currie and Crosland (2009) uttered that eating habits must be goal directed towards performance enhancement and it is very important to pay attention on what must be eaten rather than what should be restricted. It is advisable that athletic eating is under the supervision of a qualified sports nutritionist or sports dietitian.

3.3. Bone health

The well-being and health of human skeleton is the base of improving fundamental athletic skills and therefore enhancing sport performance. Low EA and the syndrome of RED-s affect bone health in a direct way, specially concerning females (Nattiv *et al.*, 2007; Mountjoy *et al*. 2014). The components of RED-s such as LEA, low body weight/BMI, disordered eating and extreme weight loss portray risk for the development of low bone mineral density, which potentially leads to stress fracture injuries and osteoporotic fractures if LEA continues (Papageorgiou *et al.,* 2017). The peak bone mass accretion is established during childhood and adolescent years so the goal throughout adulthood is to maintain bone mineral density (BMD) (Southmayd *et al.,* 2017). Additionally, osteoporosis is not always caused by decreased bone mineral loss in adulthood but might be the consequence of insufficient accumulation of optimal BMD during childhood and adolescence (Loucks, 2004; Loucks *et al.*, 2011; Nattiv *et al.*, 2007).

Reduced energy intake causes suppression of key metabolic hormones that promote bone formation, i.e. leptin, insulin-like growth factor I (IGF-1) and total triiodothyronine (TT3) which as a result impair bone health (Mountjoy *et al.*, 2014; Nattiv *et al.*, 2007). Osteoclastic bone resorption is being upregulated due to the suppression of the hypothalamic-pitutary-ovarian (HPO) axis leads to a hypoestrogenic environment (Weitzmann & Pacifici, 2006). Oestrogen is the hormone which increases the uptake of calcium into blood and further deposition into the bone (Mountjoy *et al.*, 2014). According to Weitzmann and Pacifici (2006) oestrogen plays a fundamental role in skeletal growth and bone homeostasis in both men and women. Hereby osteoblasts, osteocytes and osteoclasts function as oestrogen receptors, these receptors are also expressed in bone marrow stromal cells (the precursors of osteoblasts), therefore decrease in oestrogen level causes negative effects on bone homeostasis and may lead to osteoporosis (Weitzmann & Pacifici, 2006). Osteoporosis is defined as ‘‘a skeletal disorder characterized by compromised bone strength predisposing a person to an increased risk of fracture’’(Nattiv *et al.*, 2007).

Like oestrogen, testosterone has also anabolic effects on bone by stimulating osteoclasts, enlarging bone formation and also calcium absorption (Mountjoy et al., 2014). While oestrogen is more associated with women, low testosterone levels is believed to be connected with male athletes’ low BMD (Hind *et al.*, 2006). Endogenous hormones oestrogens and androgens have therefore impact on bone health in both sexes (Hind *et al.*, 2006; Ihle & Loucks, 2004; Mountjoy *et al.*, 2014). Increases in the stress hormones, catecholamines and cortisol, caused by insufficient energy intake and LEA also affects bone health negatively (Fuqua & Rogol, 2013).

In addition to nutritional deficiencies, medical disorders such as hypogonadal states and hyperthyroidism also evoke osteoporosis (Nattiv *et al.*, 2007). For women, functional hypothalamic amenorrhea indicates direct decrease in bone health since Ihle and Loucks (2004) study about exercising women showed that after five days of lowered EA (less than 30 kcal $\cdot$ kg $\mathrm{FFM}^{-1} \cdot \mathrm{day}^{-1}$) the rate of bone resorption increased, and the rate of bone formation declined. Even though it was discussed to be hypoestrogenism due to menstrual dysfunction which caused low BMD, it is now recognised that prolonged restricted EA decreases IgF-1 and other bone formation marker levels and its effect could be irreversible with reductions in BMD (Fuqua & Rogol, 2013; Ihle & Loucks, 2004; Mountjoy *et al*., 2014; Nattiv *et al.*, 2007).

The screening and diagnosis of osteoporosis is based on BMD and it should be measured on whole body with DXA (De Souza *et al.*, 2017; Mountjoy *et al*., 2014; Nattiv *et al*., 2007).

Nattiv *et al.* (2007) brings out that the World Health Organisation diagnoses osteoporosis and osteopenia on the basis of T-scores, that compare individuals to average peak adult BMD (Nattiv *et al*., 2007). However, since the peak adult BMD used in T-scores about women derives from epidemiological data about Caucasian postmenopausal women, it is not suitable for premenopausal women and children (Laughlin & Yen, 1996). Thus for other population it is recommended to express BMD in Z-scores, which makes it possible to compare individuals to age and sex-matched controls. Z-score lower than -2.0 standard deviation (SD) refers to low bone density below the expected range for age or for chronological age (Nattiv *et al.*, 2007). Furthermore, as strength training leads to higher BMD, athletes have considerably higher BMD than non-athletes and therefore Z-score lower than only -1.0 SD is a risk factor for fragility fractures (Nattiv *et al.*, 2007). Taken together, among athletes a Z-score value between -1.0 and -2.0 is considered as low BMD and a value below -2.0 SD is adequate for the diagnosis of osteoporosis (Mountjoy *et al.*, 2014).

3.4. Reproductive function

Another function affected by RED-s is the work of hypothalamic-pituitary-gonadal axis, which glands produce gonadotropin-realising hormone, luteinizing hormone (LH), follicle-stimulating hormone (FSH), and control the production of oestrogen and testosterone. These hormones are responsible for reproductive function in both men and women, though the relation between men, their reproductive disturbances and LEA has very little research and proof (Mountjoy et al., 2014). Number of female athletes suffer from hypothalamic amenorrhea because of LEA (Fortes *et al.*, 2014; Nattiv *et al*., 2007), but Hackney *et al.* (2005) has emphazised that there are changes in hypothalamic-pituitary-gonadal (HPG) axis hormones that influence reproduction and metabolism due to high EEE and insufficient EI in men also (Hackney, 2008; Hackney *et al*., 2005; Tenforde *et al.*, 2016).

Disturbances in menstrual function is very high among athletes, specially in endurance and aesthetic events. The Triad represents and accentuates this problem importantly and RED-s states the female individuality to a great extent (Nattiv *et al.*, 2007; Mountjoy *et al.*, 2014). Because of the survival instincts of human and specially females, many physiological functions extenuate in order to survive and reproduction is the first function that gets affected (Wade *et al.*, 1996). Wade and colleagues (1996) have emphasized that reproduction is extremely sensitive to EA and due to limited food intake reproductive attempts are suspended in favour of processes necessary for individual survival. Females often suffer from amenorrhea due to low EA and insufficient EI (Fortes *et al.*, 2014; Nattiv *et al.*, 2007).

Menstrual disorders in athletes range from anovulation, oligomenorrhea to amenorrhea, which may all cause infertility (Figure 3). The indicators of amenorrhoeic athlete are low plasma glucose concentration, low insulin, low IGF-1, low leptin, low TT3, low resting metabolic rates, elevated growth hormone (GH) and mildly elevated cortisol (Laughlin & Yen, 1996). According to Loucks (2004) all these abnormalities are signs of chronic energy deficiency.

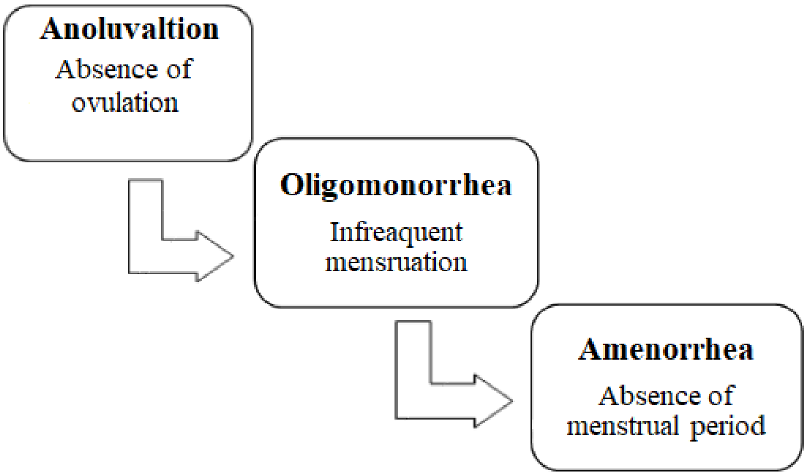


Figure 3. Menstrual disorders in athletes range from anovulation, which is the absence of ovulation or irregularity of menstrual periods, oligomonorrhea – infreaquent menstruatiton, to amenorrhea – the absence of menstrual period which likely occurrs with infertility.

In male athletes, it is noticed a decrease in the level of testosterone and other reproductive hormones such as LH and FSH (Tenforde *et al*., 2016). Hackney and colleagues (2005; 2008) have introduced a phrase „exercise-hypogonadal male", which is low basal resting testosterone level condition endurance athletes often present. In addition to low testosterone level, exercise-hypogonadal male also show a decline in LH and prolactin (Hackney, 2008). Although there are alterations in the HPG axis in men but there is still not enough evidence to draw a parallel between the negative consequences of RED-s' reproductive function in men and women (De Souza *et al.*, 2017; Tenforde *et al.*, 2016).

4. DIFFERENT SPORT SPECIALITIES AND THE PREVALENCE OF RED-S

Since RED-s is only gaining acknowledge around athletes and sports environment, there haven't been done many studies about it's prevalence in different sports but considering all the symptoms and other factors relevant to RED-s, it is possible to estimate it's occurrence among different sports and athletes. Some screening instruments do exist but there is no consensus on the efficiacy of the tools so when an athlete presents with DE/ED, weight loss, lack of normal growth and development, menstrual dysfunction, recurrent injuries and illnesses, decreased performance or mood changes it is considered to diagnose RED-s (Mountjoy *et al.*, 2014).

Athletes who train and compete in sports that have high EEE (for example endurance sports) are in higher risk of developing TRIAD or RED-s. The body weight of an athlete can influence training and performance in many sports and problematically in some sports, competition weight might be lower than everyday weight. In many cases the actions pursuing towards ideal weight or competition weight endangers the health of the athlete (Currie & Crosland, 2009). Nevertheless, even though body mass and body composition are easy to be manipulated, it should be reminded that no strict body composition guidelines apply for all athletes (Thomas *et al.*, 2016).

4.1. Endurance sports

Endurance athletes have extremely high training volume and therefore experience high EEE. This is also a reason why the relative incidence of RED-s is the biggest among endurance athletes, such as cyclist, distance runners, cross-country skiers. Endurance athletes benefit from low energy cost of movement and a favourable ratio of weight to surface area for heat dissipation (Thompson *et al.*, 2016). Studies about cyclist have concluded evidently low energy intake taking into account their level of training, vitamin level below recommendations and elevated DE behaviours (Tenforde et al., 2016). Although, studies about cyclist and runners have also found as many as endurance athletes are in energy deficit, during and surrounding competition day caloric intake and energy cost was balanced (Tenforde et al., 2016).

4.2. Aesthetic and weight-class sports

Sports that are judged by the looks and appearance of the athlete are aesthetic sports. Such sports are gymnastics (both rhytmic and artistic), figure skating, diving and synchronised swimming, fitness and bodybuilding. According to Tompson *et al*. (2016) athletes of acrobatic sports benefit biomechanical advantages from being lean and „small" and being able to move their body in a smaller space. Weight-sensitive sports (sports involving weight divisions) such as combat sports, rowing, weight-lifting and powerlifting, judo and wrestling, athletes usually try to fit into the lowest achievable body weight category (Thompson *et al.,* 2016). Weight-sensitive sports and aesthetic athletes have extremely high per cent of using drastic weight control measures to achieve weight target prior to competition. Additionally, they suffer from chronic periods of LEA and poor nutrient support in an effort to achieve lower weight or leaner body composition. (Currie & Crosland, 2009; Sundgot-Borgen *et al.,* 2013; Thompson *et al.,* 2016).

4.3. Gravitational sports

Some sports such as ski jumping and other jumping events (long and triple jump, high jump) premises low body weight in assumption for better performance. Regrettably there are no studies about gravitational sports and RED-s, but there are evidence about world-class ski jumpers to have extremely low body mass index (BMI), also they experience unhealthy eating behaviours and ED in order to maintain low body weight (Tenforde *et al.,* 2016). Considering these findings it is believable that gravitational sports athletes may also be affected by RED-s.

5. GUIDELINES

Many publications present guidelines on how to prevent or means of treatment about mentioned health problems resulting with RED-s. It is suggested for international organisations such as National Olympic Committees or National Sport Federations to arrange preventative educational programs for athletes and coaches to increase the knowledge about RED-s, Triad and the importance of health and nutrition monitoring through training process (Mountjoy *et al.,* 2014; Sundgot-Borgen *et al.,* 2013). Kroshus *et al.* (2018) study about athletic trainers' knowledge of the Triad and RED-s summarizes that wider awareness about these problems may encourage a more comprehensive approach to the screening and treatment.

Athletes should be provided with individualized diet and training program, which takes into account individual factors such as training volume, training period and the goals of the athlete whether he/she wants to maintain/gain/lose weight. Using these strategies, losing body weight and gaining lean body can be done without negatively impacting the health and performance of the athlete (Thompson *et al.,* 2016). Energy deficit should be implemented with minimal negative effects to sport-specific training recovery (Marcason, 2016).

Furthermore, it has been counterpointed that if an athlete is diagnosed with only one of the symptoms of RED-s (ie. LEA, menstrual dysfunction, low BMD), greater attention to exploring other signs of RED-s should be taken into account (Kroshus *et al.,* 2018; Mountjoy *et al.,* 2014; Statuta *et al.,* 2017). Many symptoms for example low BMD and functional hypothalamic amenorrhea develop in a long period of time and don't show physically any signs before getting dangerous for health so early prevention and treatment is essential (Nattiv *et al.,* 2007).

In addition to early prevention and treatment, the IOC consensus statement (Mountjoy *et al.,* 2014) brings on the importance of healthcare proffessionals such as sport physicians, nutritionists, psychologysts, physiotherapists and physiologists work and support with the athlete. Surrounding medical team will definetely help in the prevention, detection and treatment of RED-s.

CONCLUSION

Relative energy deficiency in sport is an extensive underemphasized problem, specifically in endurance events (ie. distance running, cycling) and events where body weight, more precicely leanness, is considered to be performance discriminator (ie. aesthetic sports events, gymnastics, figure skating etc). Female athlete triad is the common denominator for the three components: (1) low energy availability with or without disordered eating; (2) menstrual dysfunction; and (3) low bone mineral density, which can occur in isolation as well as all three in the sequence. Over a period of time, the athlete moves along on a continuous spectrum ranging from the healthy athlete with optimal energy availability (EA), regular menses and healthy bones to the opposite end of the spectrum characterised by amenorrhea, low EA and osteoporosis. (Nattiv *et al*., 2007; Mountjoy *et al.*, 2014)

As a new dimension to the Triad, Mountjoy *et al*. (2014) in the International Olympic Comittee consensus statement introduced more comprehensive, broader terminology for the overall syndrome - relative energy deficiency in sport. Furthermore, it has been argued that a relative energy deficiency is also affecting male athletes. The underlying mechanism of RED-S is an inadequacy of energy to support the range of body functions involved in optimal health and performance in female as well as male athletes. Low energy availability, which occurs with a reduction in energy intake and/or increased exercise load, causes adjustments to body systems to reduce/conserve energy expenditure, leading to disruption of an array of hormonal, metabolic and functional characteristics. (Hackney, 2008; Mountjoy *et al.*, 2014; Loucks, 2004; Statuta *et al.*, 2017)

In the field of sports RED-s is not yet widely acknowledged problem so broadcasting the meaning and the backroung of the term RED-s is first priority in eliminating the complicative syndrome. It is important to improve the knowledge about athletes' well-being and how to maintain optimal health in the process of training and competing.The improvement lies not only in the actions of the athlete but the surrounding team – coaches, physiotherapists, nutritionists – they all need to work in the best possible use in order to achieve maximum performance goals.

REFERENCES

1) Currie A, Crosland J. Responding to eating disorders in sport – UK guidelines. Nutrition & Food Science 2009; 39:619–626.
2) De Souza MJ, Koltun KJ, Etter CV, Southmayd EA. Current status of the female athlete triad: update and future directions. Current Osteoporosis Reports 2017; 15:577–587.
3) De Souza MJ, Nattiv A, Joy E, Misra M, Williams N, *et al*. Female athlete triad coalition consensus statement on treatment and return to play of the female athlete triad. British Journal of Sports Medicine 2014; 48:289.
4) Drinkwater BL, Nilson K, Ott S, Chesnut CH. Bone mineral density after resumption of menses in amenorrheic athletes. Journal of the American Medical Association 1986; 256:380–382.
5) Fortes LS, Kakeshita IS, Almeida SS, Gomes AR, Ferreira MEC. Eating behaviours in youths: A comparison between female and male athletes and non-athletes. Scandinavian Journal of Medicine & Science in Sports 2014; 24:62-68.
6) Fuqua JS, Rogol AD. Neuroendocrine alterations in the exercising human: implications for energy homeostasis. Metabolism 2013; 62:911–921.
7) Hackney AC. Effects of endurance exercise on the reporductive system of men: the "exercise-hypogonadal male condition". Journal of Endocrinological Investigation 2008; 31:932-938.
8) Hackney AC, Moore AW, Brownlee KK. Testosterone and endurance exercise: development of the “exercise-hypogonadalmale condition”. Acta Physiologica Hungarica 2005; 92:121-137.
9) Hilton LK, Loucks AB. Low energy availability, not exercise stress, suppresses the diurnal rhythm of leptin in healthy young women. American Journal of Physiology - Endocrinology and Metabolism 2000; 278:43-49.
10) Hind K, Truscott JG, Evans JA. Low lumbar spine bone mineral density in both male and female endurance runners. Bone 2006; 39:880–885.
11) Ihle R, Loucks AB. Dose-response relationships between energy availability and bone turnover in young exercising women. Journal of Bone and Mineral Research 2004; 19:1231-1240.
12) Johnson C, Powers PS, Dick R. Athletes and eating disorders: the National Collegiate Athletic Association study. International Journal of Eating Disorders 1999; 26:179–188.
13) Kroshus E, DeFreese JD, Kerr ZJ. Collegiate athletic trainers’ knowledge of the female athlete triad and relative energy deficiency in sport. Journal of Athletic Training 2018; 53:51–59.

14) Laughlin GA, Yen SS. Nutritional and endocrine-metabolic aberrations in amenorrheic athletes. Journal of Clinical Endocrinology and Metabolism 1996; 81:4301-4309.
15) Loucks AB, Kiens B, Wright HH. Energy availability in athletes. Journal of Sports Sciences 2011; 29:7-15.
16) Loucks AB. Energy balance and body composition in sports and exercise. Journal of Sports Sciences 2004; 22:1-14.
17) Manore MM, Kam LC, Loucks AB. The female athlete triad: components, nutrition issues, and health consequences. Journal of Sports Sciences 2007; 25:61–71.
18) Marcason W. Female athlete triad or relative energy defecency in sports (RED-s): is there a difference? Journal of the Academy of Nutrition and Dietetics 2016; 116:744.
19) Melin A, Tornberg ÅB, Skouby S, Møller SS, Sundgot-Borgen J, *et al*. Energy availability and the female athlete triad in elite endurance athletes. Scandinavian Journal of Medicine & Science in Sports 2014; 25:610–622.
20) Mountjoy M, Sundgot-Borgen J, Burke L, Carter S, Constantini N, *et al*. The IOC consensus statement: beyond the female athlete triad - relative energy deficiency in sport (RED-s). British Journal of Sports Medicine 2014; 48:491-497.
21) Mountjoy M, Sundgot-Borgen J, Burke L, Carter S, Constantini N, *et al*. Author’s 2015 additions to the IOC consensus statement: relative energy deficiency in sport (RED-s). British Journal of Sports Medicine 2015; 49:417-420.
22) Nattiv A, Loucks AB, Manore MM, Sanborn CF, Sundgot-Borgen J, *et al.* American College of Sports Medicine position stand. The female athlete triad. Medicine and Science in Sports & Exercise 2007; 39:1867–1882.
23) Papageorgiou M, Elliott-Sale KJ, Parsons A, Tang JCY, Greeves JP, *et al*. Effects of reduced energy availability on bone metabolism in women and men. Bone 2017; 105:191–199.
24) Slater J, Brown R, McLay-Cooke R, Black K. Low Energy availability in exercising women: historical perspectives and future Directions. Sports Medicine 2017; 47:207–220.
25) Southmayd EA, Hellmers AC, Souza MJD. Food Versus Pharmacy: Assessment of Nutritional and Pharmacological Strategies to Improve Bone Health in Energy-Deficient Exercising Women. Current Osteoporosis Reports 2017; 15:459–472.
26) Statuta SM, Asif IM, Drezner JA. Relative energy deficiency in sport (RED-S). British Journal of Sports Medicine 2017; 51:1570–1571.
27) Sundgot-Borgen J, Meyer NL, Lohman TG, Ackland RT, Maughan RJ *et al*. How to minimise the health risks to athletes who compete in weight-sensitive sports review and position statement on behalf of the Ad Hoc Research Working Group on body

composition, health and performance, under the auspices of the IOC Medical Comission. British Journal of Sports Medicine 2013; 47:1012-1022.

28) Sundgot-Borgen J, Torstveit MK. Aspects of disordered eating continuum in elite high-intensity sports. Scandinavian Journal of Medicine & Science in Sports 2010; 20:112–121.
29) Tenforde AS, Barrack MT, Nattiv A, Fredericson M. Parallels with the female athlete triad in male athletes. Sports Medicine 2016; 46:171–182.
30) Thomas DT, Erdman KA, Burke LM. Position of the Academy of Nutrition and Dietetics, dietitians of Canada, and the American College of Sports Medicine: nutrition and athletic performance. Journal of the Academy of Nutrition and Dietetics 2016; 116:501–528.
31) Thompson A, Petrie T, Anderson C. Eating disorders and weight control behaviors change over a collegiate sport season. Journal of Science and Medicine in Sport 2017; 20:808–813.
32) Wade GN, Jones JE. Neuroendocrinology of nutritional infertility. American Journal of Physiology: Regulatory, Integrative and Comparative Physiology 2004; 287:1277– 1296.
33) Wade GN, Schneider JE, Li HY. Control of fertility by metabolic cues. American Journal of Physiology 1996; 270:1-19.
34) Weitzmann MN, Pacifici R. Oestrogen deficiency and bone loss: an inflammatory tale. The Journal of Clinical Investigation 2006; 116:1186–1194.
35) Yeager KK, Agostini R, Nattiv A, Drinkwater B. The female athlete triad: disordered eating, amenorrhea, osteoporosis. Medicine & Science in Sports & Exercise 1993; 25:775-777.

RESÜMEE

Suhteline energia defitsiit spordis tähendab ebapiisavat kaloraaži ja ülisuurt energiakulu käsikäes. See on seisund, mis kujuneb organismi pikaajalisel enegiadefitsiidis hoidmisel. Tavapärasest energiadefitsiidist erineb suhteline energia defitsiit selle poolest, et sportlane saab piisavalt toitaineid taastamaks treeningul kaotatud energiavarud, ent puudu jääb organismi füsioloogilistele funktsioonidele vajaminevast energiast. Füsioloogilised puudused organismis võivad suhtelise energia defitsiidi väljaarenemist soodustada ning ühtlasi ka selle tagajärjel süveneda. Suhtelist energia defitsiiti põevad peamiselt vastupidavusala sportlased, kelle energiakulutus on kahtlemata üks suurimaid ja samuti sportlased, kelle spordiala tulemus on korrelatsioonis kehakaaluga või mille puhul hinnatakse sportlase keha esteetilisust.

Põhjus on lihtne: suur kehaline aktiivsus tagab energiakulu, mida sportlased hiljem toiduga täielikult ei taasta. Pikemaajaliselt põhjustab selline seisund organismis muutusi, mida inimene silmaga ei näe ega pruugi tajudagi. Andmeid leidub sellel teemal senimaani rohkem naistest, kuna mõiste suhteline energia defitsiit spordis pärineb eelnevalt rohkelt kõneainet ja uurimismaastikul kinnitust leidnud naissportlaste triaadsündroomist (*Female Athlete Triad*). Triaadsündroom on haiguslik seisund, mis hõlmab naisi, kellel esineb madal energiasaadavus, menstruaaltsükli väärtalitlus ja vähenenud luutihedus.

Naissportlasi kimbutav triaadsündroom avastati juba 1997. aastal, mil sarnaste sümptomitega naiste seisundit hakatigi kirja panema kui naistriaadi. Teadlaste poolt kogutud andmete põhjal on aga põhjust arvata, et sarnased sümptomid esinevad ka meestel. Kuna meeste puhul ei saa kasutada terminit naistriaad, võeti lisaks kasutusele laialdasem väljend suhteline eneriga defitsiit, mis hõlmab nii mees- kui naissportlaste seisundit.

Suhteline energia defitsiit on terviseriskiga seisund, mida kohtab kõrge kehalise aktiivsusega tippsportlastel ja spordiharrastajatel. Tegemist on viimastel aastatel avastatud sündroomiga, mistõttu spordirahva teadlikkus sellest pole väga suur. Seetõttu on oluline, et sportlastele ja ka treeneritele oleks toitumisalane nõustamine ja info treeningutega käsikäes. Laialt levinud tervisliku toitumise nõuanded ei pruugi tugevalt treeniva sportlase puhul paika pidada ja seepärast võib suhteline energia defitsiit kimbutada ka neid, kes endi arvates toituvad korrapäraselt. Tegemist on probleemiga, millele nii tippsportlased kui ka harrastajad peaksid tähelepanu pöörama. Suhteline energia defitstiit võib pikemaajaliselt tekitada väga raskeid tervislikke seisundeid, mistõttu ei tohi sellesse suhtuda kergekäeliselt.

COPYRIGHT FORM

Mina Krete Junson

(autori nimi)

(sünnikuupäev: 07.08.1995)

1. annan Tartu Ülikoolile tasuta loa (lihtlitsentsi) enda loodud teose

Relative energy deficiency in sport,

(lõputöö pealkiri)

mille juhendaja on Martin Mooses ,

(juhendaja nimi)

1.1. reprodutseerimiseks säilitamise ja üldsusele kättesaadavaks tegemise eesmärgil, sealhulgas digitaalarhiivi DSpace-is lisamise eesmärgil kuni autoriõiguse kehtivuse tähtaja lõppemiseni; 1.2. üldsusele kättesaadavaks tegemiseksTartu Ülikooli veebikeskkonna kaudu, sealhulgas digitaalarhiivi DSpace´i kaudu kuni autoriõiguse kehtivuse tähtaja lõppemiseni.

2. olen teadlik, et punktis 1 nimetatud õigused jäävad alles ka autorile.

3. kinnitan, et lihtlitsentsi andmisega ei rikuta teiste isikute intellektuaalomandi ega isikuandmete kaitse seadusest tulenevaid õigusi.

Tartus, 07.05.2018 (kuupäev)