Oura ring as a monitoring tool in elite female ice hockey players

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Abstract

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Monitoring athletes stress and recovery have gained its popularity in high performance sports. For effective monitoring it is important to find the most suitable and reliable methods for the athletes. The purpose of the study was to assess the functionality of Oura ring in a use of female elite ice hockey players. The other objective was to collect data of the players individual training, alcohol consumption and possible injuries/illnesses during their usual training cycle for the use of Oura Health.

The subjects of the study were nineteen (19) ice hockey players with an average age of 22,1 years from Oulun Kärpät Naiset team, playing in the Finnish Women's National league. The players training load, perceived fatigue, sleep quality and muscle soreness were collected from six (6) weeks from September 2018 to November 2018 through Webropol surveys and Resting Heart Rate (RHR) and Heart Rate Variability (HRV) were measured by using Oura wellness ring. Pearson correlation analysis was used to examine the relationship between training load, (from the previous day, 4 days acute training load and 2 weeks chronic training load) the daily wellness-assessment average and the nightly Oura data. The relationship of Oura ring variables were also examined.

The effect of training load did not have significant correlation on RHR and HRV when the full data was examined. There were neither a relationship between the wellness-assessment and RHR and HRV. When examining the individual data for some players there were medium to high correlation but for some players there were no correlation at all. There was also a strong significant relationship between RHR and HRV examined from Oura ring. This study shows that there is low but significant correlation between the training load and the wellness- assessment.

This study confirmed that morning-measured ratings of fatigue, sleep quality and DOMS are probably more sensitive to the changes in training load than the Oura ring HR- derived parameters. Oura ring could provide useful information for some individuals about overall recovery, but it should be combined with subjective measures. In future, the possible measuring errors should also be reconsidered, and the players needs to be familiarized well with the use of Oura ring and Oura Cloud. The user experience showed that the players benefited from the information given from the ring and that the sleep tracking was the most appreciated feature.

Keywords
Oura ring, monitoring tool, recovery, female ice hockey players

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1 Introduction

Monitoring athletes stress and recovery have gained its popularity in high performance sports. With an increasing training loads and high levels of stress from different components, it is necessary to manage risks associated with the possible negative consequences and to maintain optimal psychological and physiological wellbeing of an athlete. (McGuigan 2017, 1-6.) There are a wide range of different monitoring tools available and numerous of factors determining the appropriate tools to ensure a positive effect on athlete’s life. A guarantee for a comprehensive monitoring process comes by considering both objective and subjective monitoring instruments. An individual approach to athlete monitoring has found to bring up the most benefits from a training system. (Kellmann, Kellmann et al. 2018, 9-14.)

A successful monitoring of an athlete will provide useful information about the recovery status of the athlete and aid in designing effective training programs. An optimal recovery-stress balance will ensure a good athletic performance, whereas the mistaken ratio between load and recovery can impair the performance and increase the risk of developing non-functional overreaching, illness, and/or injury. (Kaikkonen 2017, 30.)

The objective of the study was to assess the functionality of Oura ring in a use of female elite ice hockey players. The Oura ring is a wellness ring featuring scientifically validated sleep tracking, providing night time heart rate and heart rate variability and activity tracking. Oura ring measures the body signal data with three types of sensors. The signals that Oura ring processes are: Interbeat interval (IBI), pulse amplitude variation, ECG level resting heart rate (RHR), heart rate variability (HRV), respiratory rate, movements, intensity of physical activity and body temperature deviation. (OuraHealth2018.)

The subjects of the study were female elite ice hockey players from team Oulun Kärpät Naiset, playing in the Finnish Womens National League. In Finland, most of the female players are either studying or working together with their playing careers and it causes an enormous challenge in controlling the overall stress and recovery of the players. As the Finnish Women’s hockey league is raising its level year by year, it forces the teams to improve their activities to enhance both training and recovery of the athletes.

Another objective was to collect reliable data of the individual training (daily training or game session duration, content of each session, time of the session), alcohol consumption and possible injuries/illnesses for the use of Oura Health. The company will use the information for their future research and development of the product.

The study started on August 2018 when the subject group players were given an Oura wellness ring for a four (4) months period. The players could use the ring independently and get daily data of their sleep and recovery. The players signed a permission that their individual data can be collected and analyzed from the Oura Cloud by the authorized persons including the coaching staff, researchers and the author of the thesis. During the study the players were asked to fill out a training diary with the perceived ratings of exertion and a questionnaire of their perceived ratings of wellness for eight weeks period. The aim was to collect data with different monitoring tools and compare it to the data given from the Oura ring. In the end of the research the collected data and the training diaries will be given to Oura Health as an anonymous package. The players were able to resign from the research at any time and cancel the permission for their data with no argumentation.

This study tested the hypothesis of relationship between training load, perceived ratings of wellness and Oura ring data. The individual training load was monitored daily via online questionnaire, the psychometric online questionnaire was used to assess general indicators of players wellness and comprised of three questions relating to perceived overall fatique, sleep quality and delayed-onset muscle soreness (DOMS). The examined data from Oura ring were the nightly Heart Rate Variability, average Resting Heart Rate and lowest Resting Heart Rate.

2 Monitoring training and recovery in athletes

Athlete monitoring has become a common element in elite level sports. Nowadays it is rare that a high-performance sporting program doesn't use any monitoring system. Many companies in a field of sport, wellness and technology target the athlete monitoring market. Therefore, it is important that those practitioners working in sport industry need to be familiar with the principles of athlete monitoring. (McGuigan 2017, 1-6.) Technology has brought the monitoring available for everyone, but for analysing the data there needs to be understanding of the physiologic background, the possible sources of errors behind the measuring and the practical implications of the collected data (Kaikkonen 2017, 33).

2.1 Why monitor athletes?

The ultimate outcome in sport is performance and it should be kept as an underlying consideration for a monitoring program. The key purpose of monitoring is to find out the stress response to individual training sessions that builds up the overall training program. Practitioners need to know the overall dosage of load that consist training load, competition load and life load. (McGuigan 2017, 1-3.) Appropriate load monitoring can aid in determining whether an athlete is adapting to a training program and in minimizing the risk of developing non-functional overreaching, illness, and/or injury (Halson 2014, 139-147). Monitoring helps determine the athletes´ training readiness and to adjust the the training session for the individual athlete (McGuigan 2017, 1-3). Figure 1. depicts monitoring issues and how monitoring helps athletes.

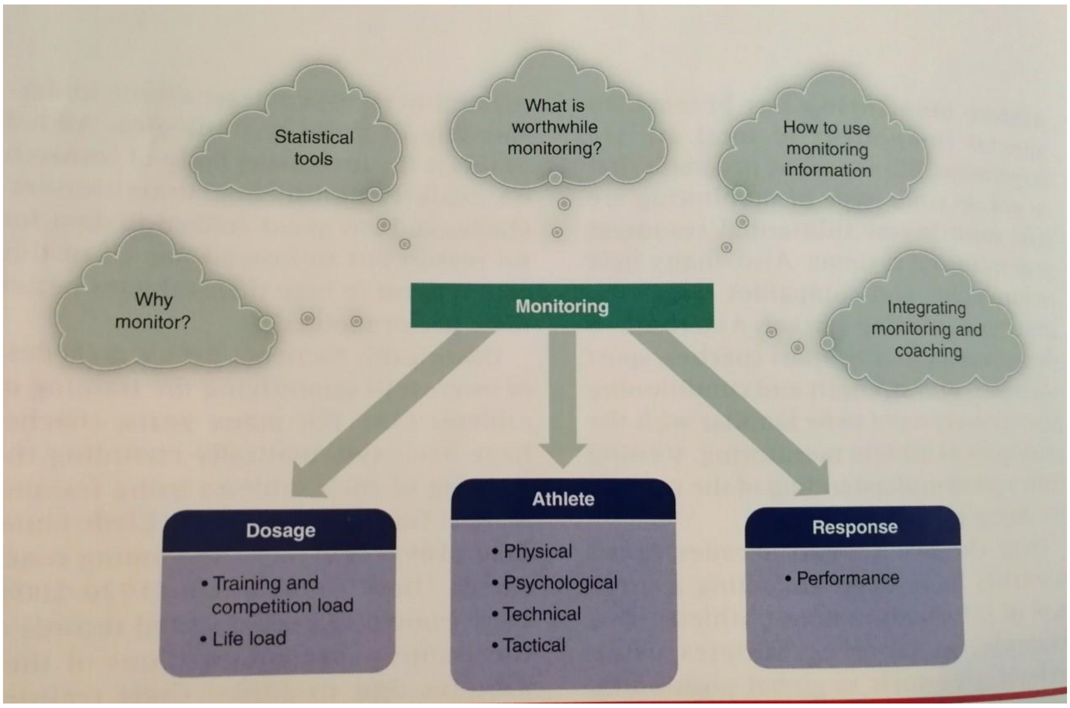

Figure 1. Monitoring issues and how monitoring helps athletes (McGuigan 2017, 2).

2.2 Monitoring tools

A guarantee for a comprehensive monitoring for athletic performance comes by considering both objective and subjective monitoring instruments (Kellmann, Kellmann et al. 2018, 9). Performance indicators can be measured through parameters such as countermovement jumps, multiple rebound jumps, or the performance requirements can be determined e.g., via the maximal oxygen uptake or the lactate threshold (Kellmann, Kellmann et al. 2018, 9). A health status such as nutrient deficiency as well as hormonal or inflammatory parameters can be detected via blood measures. High costs and the accessibility in daily basis restrain the applicability of some of these measures. (Kellmann, Kellmann et al. 2018, 9.) Other monitoring tools used by high-performance programs include heart rate recovery, neuromuscular function, biochemical/hormonal/immunological assessments, questionnaires and diaries, psychomotor speed, and sleep quality and quantity. The monitoring approach taken with athletes may depend on whether the athlete is engaging in individual or team sport activity; however, the importance of individualization of load monitoring cannot be over emphasized. (Halson 2014, 139-147.)

The subjective measures have found to be even more sensitive and consistent in reflecting acute and chronic training loads compared to objective procedures. These findings referred to the monitoring of both perceived stress and recovery and mood disturbances. (Kellmann, Kellmann et al. 2018, 10.) The overall stress is not only caused by the sport-specific stressors, but also emerged from personal or social factors. (Kellmann, Kellmann et al. 2018,12.) This is why athlete monitoring should not limit to either subjective or objective measures, instead they can be used to complement each other (Saw, Main, Gastin 2016, 281–291).

There is still no agreement that the best or the most practical singular parameter is present (Kellmann, Kellmann et al. 2018, 9). An individual approach to athlete monitoring brings up the most benefits from a training system (McGuigan 2017, 1-6). As the authors (Kellmann, Kellmann et al. 2018, 14) regards, the constant exposition to performance tests and the awareness of continuous observation may overstress the athletes, and then the monitoring of stress may become a stressor itself. The carefull planning and implementation of the chosen monitoring methods will determine whether the results will positively affect an athlete's training program (McGuigan 2017, 1-6).

2.3 Recovery-stress balance

The monitoring tools can provide useful information about the recovery status of the athlete (Kaikkonen 2017, 30). The ideal intensity, timing and frequency of exercises can be personalised depending on the individual recovery-stress balance (Kellmann, Kellmann et al. 2018, 9). Optimal training load leads to improvements in performance whereas the mistaken ratio between load and recovery can impair the performance (Kaikkonen 2017, 30-33). The basic idea of recovery is that resources need to be restored to regain a homeostatic and biorhythmic balance (Kellmann, Kellmann et al. 2018, 5).

Quantifying the training load of an athlete and its relationship to performance outcomes should be a priority to maximize the effectiveness of training and achieve peak performance (Kellmann, Kellmann et al. 2018, 132). The measuring should be done by comparing both, the external training load such as the time&distance covered, total elevation gain etc, and the internal working load which assesses the biological stress imposed by the training session (Kellmann, Kellmann et al. 2018, 133).

The interrelation between stress states and recovery demands needs to be balanced for optimal performance. When the balance is compromised, the athletes are more likely to perform poorly. (Kellmann, Kellmann et al. 2018, 64-65.) The symptoms of underperformance can be prevented by monitoring the current levels of recovery and stress and detecting the problems before they decrease the performance (Kellmann, Kellmann et al. 2018, 70). It is now well-established that optimal recovery from practice or matches plays a major role on team sport performance. During competitive periods and tournaments, where players may compete numerous times over a few days, enhancing recovery may provide a decisive advantage for subsequent performance. Top level players dedicate a much higher proportion of their daily time in recovery than they do in practice. (Calleja-González, Mielgo-Ayuso, Sampaio, et al. 2018, 545-550.) Figure 2. shows the factors that affect training load and their relationship to overreaching, overtraining, illness, and injury.

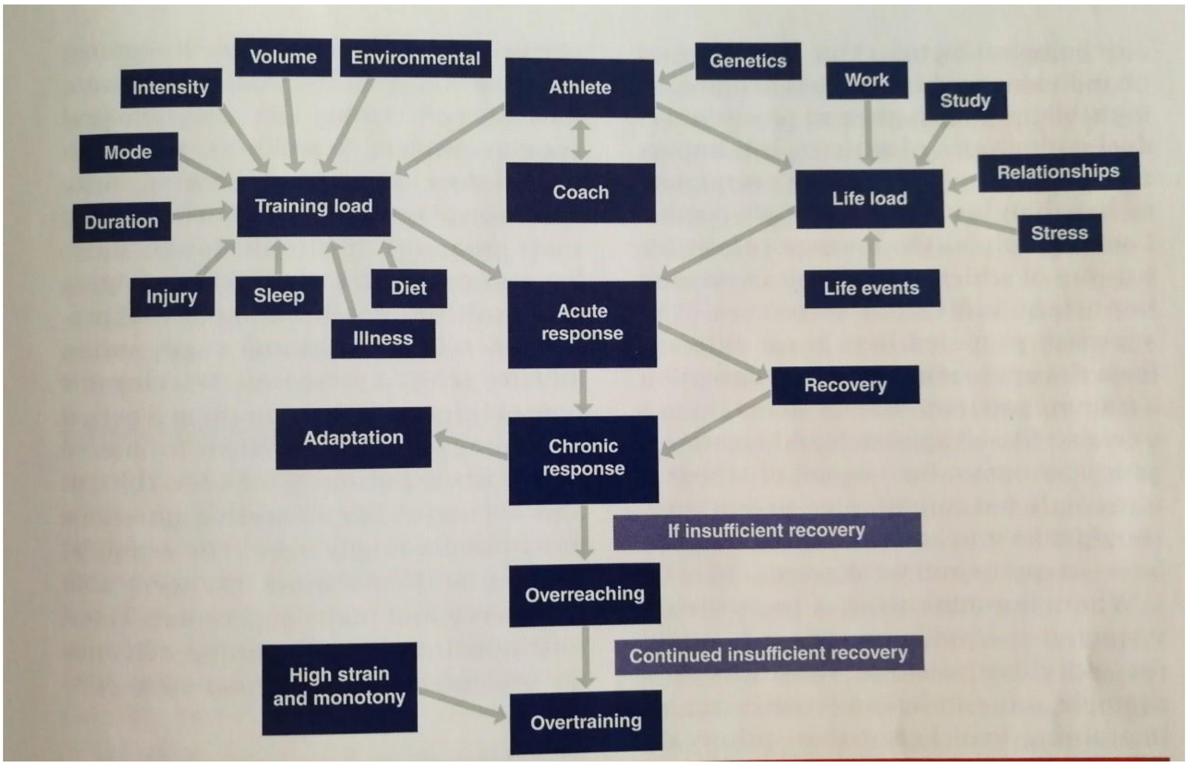

Figure 2. Factors that affect training load and their relationship to overreaching, overtraining, illness, and injury (McGuigan 2017, 7).

2.3.1 Autonomic nervous system

The autonomic nervous system (ANS), also known as the viscelar or involuntary nervous system (McCorry L.K 2007, 78) regulates homeostatic function of the body (Nummela A. et al. 2017, 7). The ANS functions without conscious, voluntary control and it influences the activity of most tissues and organ systems. It innervates cardiac muscle, smooth muscle, and various endocrine and exocrine glands and controls heart rate (HR), blood pressure, thermoregulation, respiratory airflow, focusing of the eyes, digestion, energy metabolism, defecation and contraction of the urinary bladder. (McCorry 2007, 78.) ANS has two distinct divisions, a parasympathetic (rest) and a sympathetic (activation) branch (OuraHealth, 2018). Both systems are tonically active, providing some degree of nervous input to a given tissue all the time. Because of these two divisions typically have opposing effects on a given tissue, the activity of one system may be either enhanced or inhibited. (McCorry 2007, 78.)

2.3.2 Heart rate and Heart Rate Variation

A healthy heart is not a metronome, it consists changes in the time intervals between consecutive heartbeats called interbeat intervals (IBIs). Heart rate (HR) is the amount of heart beats per minute. The fluctuation in the time intervals between adjacent heartbeats is called heart rate variability (HRV). HRV reflects regulation of autonomic balance and is sensitive to changes in homeostasis of the body. (Shaffer& Ginsberg 2017, 258.) The short-termHRV (ST, ~5 min) is influenced by the autonomic, cardiovascular, central nervous, endocrine, and respiratory systems, and baroreceptors and chemoreceptors. The 24 hour HRV is contributed by circadian rhytms, core body temperature, metabolism, the sleep cycle and the renin–angiotensin system. (Shaffer& Ginsberg, 2017, 258.)

Physiological functions such as heart rate is controlled by autonomic nervous system with interaction between the sympathetic and parasympathetic nervous systems. During training, heart rate responds to stress and rest in a nonlinear manner. Heart rate increases during high-intensity work (sympathetic response) and decreases during recovery (parasympathetic response). (McGuigan 2017, 114.)

2.3.3 Definition of Stress and Recovery

By the General Adaptation Syndrome Model (GAS), stress is considered as a disruption of the body´s homeostatic state (McGuigan 2017, 44). In sport environment, stress combines the external and internal training and competition loads and the other life demands (Kelmann, M. et al. 2018, 240-244). The combination of reactions to stress, also known as “fight-or-flight” response has evolved as a survival mechanism to people and other mammals. It enables the body to react quickly to life threatening situations. The acute stress reaction causes physiological symptoms as the heart rate and blood pressure go up and breathing becomes faster. Stress produces hormonal changes and increases the activity of sympathetic nervous system and decreases the activity of parasympathetic nervous system. (Harvard Health Publishing, 2018.) The International Olympic Committee has defined training load as “the cumulative amount of stress placed on an individual from a single or multiple training sessions (structured or unstructured) over a period of time”. (Kellmann, Kellmann et al. 2018, 74.)

Kellmann, et al (2018, 240-244) regards recovery as a multifaceted (eg, physiological, psychological) restorative process relative to time. Fatigue develops of a continuum of tiredness due to physical or mental effort, when an individual´s recovery status is disturbed by internal or external factors. Fatigue can be compensated with recovery, by regaining the balance on a physiological and psychological level. Recovery consist different modalities such as regeneration or psychological recovery strategies. (Kellmann, et al, 2018, 240-244.) When the recovery occurs, the parasympathetic nervous system is active and promotes the “rest and digest” response that calms the body down (Harvard Health Publishing, 2018).

2.3.4 Overtraining, overreaching

The basic overload principle of training states that training load should be high enough to disturb the homeostasis of the body (Nummela. et al. 2017, 7-13). If the training load stays high for a prolonged time and there are not enough time to recover, a person will start to suffer of underrecovery. It means that the overall load overpass the recovery and is also called overreaching. (Uusitalo. A. 2015, 2344-50.) Functional overreaching, a short term reduction in performance leading to performance improvements after a period of rest, is commonly used in elite level sports (McGuigan 2017, 54-55).

Overtraining syndrome is a result of excessive physical or psychologial load in relation to individual adaptability. Metabolism is mostly disruptive and there are an ”alarm condition” in the body. It takes few weeks to even several months rest to recover from a overtraining syndrome. Nutritional deficiences and/or too little energy intake, lack of sleep and short recovery times have been connected to be major factors behind overtraining. (Uusitalo 2015, 2344-50.) Kellmann, Kellmann et al. (2018, 70) presents that ”There is a general consensus among researchers that the best way to deal with overtraining and underperformance is to prevent it from happening”.

3 Athlete monitoring in team sports

The greatest challenge in athlete monitoring in team sports is the number of athletes. In team sport scenarios there can be up to 30 to 50 athletes training/practising at the same time. Large number of athletes increases the costs of monitoring tools, and the time of the practitioner is another restrictive fact when developing a monitoring system. This makes the large-scale monitoring difficult, so the practitioners often stick to simple, but still effective methods. (McGuigan 2017, 190-191.)

There is no single monitoring tool to provide a complete picture of a team sport athlete, so the practitioner should use a mixed-methods approach and develop a toolbox of different monitoring methods that fits the target group (Thorpe.R. et al. 2017, 2-28). Performance is the ultimate indicator of physical and psychological well-being and the athlete's readiness to compete, yet it is impractical to test athletes daily via performance tests (Saw et. al. 2015, 281–291). Prospective tools should be considered to be non-invasive, easy and quick to administer and limit any additional loading on the athlete (Thorpe et al. 2017, 2-28). The main focus should be put to manage the training load, reduce the injuries and illness, and optimize the performance of the team sport athletes. The monitoring methods needs to be familiarized and explained well to the athletes, so the athletes will approve the idea. This helps with compliance to the observing and improves the quality of the monitoring data. (McGuigan 2017, 200-201.)

3.1 Monitoring practises in team sports

Quantifying the training load of an athlete and its relationship to performance outcomes should be a priority to maximize the effectiveness of training and achieve peak performance (Kellmann, Kellmann et al. 2018, 132). The measuring should be done by comparing both, the external training load such as the time&distance covered, total elevation gain etc, and the internal working load which assesses the biological stress imposed by the training session (Kellmann, Kellmann et al. 2018, 133).

In team sports settings the athletes individual training load can be calculated with a training diary that includes a place to record each sessions duration, content of the session and rating of perceived exertion (RPE) (McGuigan 2017, 190). Wellness questionnaires are used to measure the overall wellness and quality of sleep, muscle soreness, fatique and stress. This will give a sight to modify the next training session with respect of the results. (McGuigan 2017, 197.) Monitoring with global positioning systems (GPS) and accelerometry devices are used widely in high-performance sport. Those have found to be reliable and potential as a field-based tool for athlete monitoring. (McGuigan 2017, 152.) Wearable technologies are another increasing trend in exercise and sport science (McGuigan 2017, 136). Those have been developed to provide a constant feedback during activities and some activity monitors have investigated for monitoring sleep in athletes. Ideally, those wearable sensors should be easy to use, small, lightweight and inexpensive. (McGuigan 2017, 154-155.) Other common monitoring practices in team sports are biochemical and hormonal markers, performance tests, movement screening and neuromuscular assesments (McGuigan 2017, 138). Figure 3. shows the common athlete monitoring practices.

TABLE 6.1 Common Athlete Monitoring Practices

Monitoring variable	Level of use	Level of evidence	Practical value
GPS and accelerometry	High	Moderate	Moderate to high
RPE	High	High	High
Wellness questionnaires	High	High	High
Biochemical and hormonal markers	Low	Moderate	Low
Heart rate measures	High	Moderate to high	Moderate to high
Performance tests	Moderate	Moderate	Moderate
Movement screening	High	Low	Moderate
Neuromuscular assessments (e.g., jumps)	Moderate	Moderate	Moderate

Based on published reports from Akenhead and Nassis (3), McCall et al. (94), Saw et al. (127), and Taylor et al. (141).

Figure 3. Common athlete monitoring practices (McGuigan 2017, 138).

3.2 Ice Hockey – physiological demands

It has been stated that ice hockey is the fastest game in the world played on two feet. When compared with other team sports, some authors have suggested that ice hockey predisposes an athlete to premature and chronic fatigue. (Cox, Miles, Verde et. al. 1995, 184.) Ice hockey is characterized by its high intensity intervals at maximal capabilities, rapid changes in velocity and duration, and frequent body contact. In a 60-minute game, a typical player performs 15 to 20 minutes playing time divided in a 30 to 80 seconds shifts with 3 to 5 minutes recovery between shifts. The continuous high intensity bursts require the player to develop both aerobic and anaerobic capacities, and the game itself require muscle strength, power, agility and flexibility. (Montgomery 1988, 99-126.) Correspondingly, appropriate training and maintenance of sport-specific fitness levels may help prevent injury and offset premature fatigue to maintain performance (Cox et.al 1995).

The game and skill performances involve short-term, maximum power efforts that require the energy directly in muscle´s adenosine triphosphate (ATP) and creatine phosphate (CP) -stocks supplied to the muscle tissue. In a maximum performance these stores last only for few seconds, so the energy required to continue the work is then obtained through anaerobic glycolysis. The anaerobic glycolysis consists 60–70 percent of the total energy production during a single shift and therefore, a player's anaerobic performance must be good. If the shifts become too long or the recovery between the shifts are too short, the muscles begin to accummulate lactic acid and as the acidity increases the fatique increases. The lactate removal is much slower than a reconstitution of a creatine phosphate, so the formation of lactic acid should be minimized. (Summanen& Westerlund 2001, 8-12.)

The stress level in which the anaerobic metabolism and lactic acid start to affect the muscles metabolism is called the anaerobic threshold. At the level of anaerobic threshold, the buffering and break down of the lactic acid is at the same level as the formation of the lactic acid. Therefore, the anaerobic threshold is a good performance indicator of a hockey player. The higher the anaerobic threshold, the more likely a player will be able to maintain a high intensity and skill performance during a game. (Summanen& Westerlund 2001, 8-12.) The anaerobic threshold is highly correlated to the distance running performance as compared to maximum aerobic capacity or VO2 max for a long time delays the metabolic acidosis. Anaerobic threshold can also be determined from the speed-heart rate relationship, without undergoing sophisticated laboratory techniques. (Asok Kumar Ghosh 2004, 24-36.)

The stress of a game has also been studied by monitoring heart rates. The heart rate provides an overall picture of stress level and, in particular, the level at which aerobic energy production occurs. In a ice hockey game, the average working heart rates of the players vary between 170 – 174 bpm (beats per minute). For defensemen, the working heart rates are on average 10 – 15 bpm less than those for forwards. (Summanen& Westerlund 2001, 8-12.)

3.3 Female ice hockey players

Despite impressive numbers of ice hockey participants, there is little research examining elite female ice hockey players. In a study of elite female ice hockey players who were trying out for the 2010 U.S. Women's Ice Hockey team, there is a characterization of twenty-three women who participated in the study and were evaluated on: body mass (kg), height (cm), age (y) vertical jump (cm), standing long jump (cm), 1 RM front squat (kg), front squat/body mass (%), 1 RM bench press (kg), bench press/body mass (%), pull ups, and body composition (% body fat). This study can help comparing future teams to these indicators and designing programs that will enhance the performance of female ice hockey players. (Murray& Ransdel 2011, 2358-2363.) Figure 4. shows anthropometric and fitness characteristics of elite female ice hockey players from the United States.

In Finland the Women's League consists ten (10) teams that play a double series of games in regular season 2018-2019. Play offs are played in a triple series after the regular season. The games are mostly played during weekends, one or two games on consecutive days. The play offs are played during weekdays and weekends. The season lasts from September to April, depending of the final placement of the team. (Leijonat 2018.)

In a regular week, a women's team trains from three to five practices together and some of the players join the club's morning practices one to three times a week. The physical part of training consists on-ice training, strength, endurance, speed and agility, and flexibility training. (Oulun Kärpät Naiset 2018.) Figure 5. shows the training summary on season 2017-2018.

Anthropometric/Fitness Characteristics	Elite Female Ice Hockey Players M ± SD and Range (Low to High Value)	Other Female Athletes
Body Mass (kg) (n = 23)	70.4 ± 7.1 (58.5 - 85.2)	**Geithner et al. (2006)** Competitive Canadian Female Ice Hockey Athletes (n = 112)[c]: 66.4 ± 6.9 kg
Height (cm) (n = 21)	169.7 ± 6.9 (152.4 - 182.9)	**Geithner et al. (2006)** 167.9 ± 5.3 cm
Vertical Jump (cm) (n = 23)	50.3 ± 5.7 (41.9 - 62.2)	**Competitive College Female Athletes**[a] 44 - 53 cm **Geithner et al. (2006)** 43.1 ± 4.9
Standing Long Jump (cm) (n = 21)	214.8 ± 10.9 (198.1 - 241.3)	**90th percentile for Female College Athletes**[a] 315 cm
1 RM Front Squat (kg) (n = 20)	88.6 ± 11.2 (74.8 - 115.7)	**90th percentile for Female College Athletes (Back Squat)** [a] Basketball: 81 kg Softball: 84 kg Swimming: 66 kg Volleyball: 84 kg
Front Squat/Body Weight (%) (n = 20)	127.7 ± 16.3 (107.0 - 165.0)	
1 RM Bench Press (kg) (n = 22)	65.3 ± 12.2 (43.1 - 88.4)	**90th percentile for Female College Athletes**[a] Basketball: 56 kg Softball: 53 kg Swimming: 53 kg Volleyball: 51 kg **Baker & Fagan**[b] 24 Female Provincial Hockey Players: 53.8 kg

Figure 4. A Physical Profile of Elite Female Ice Hockey Players from the United States (Murray & Ransdel 2011).

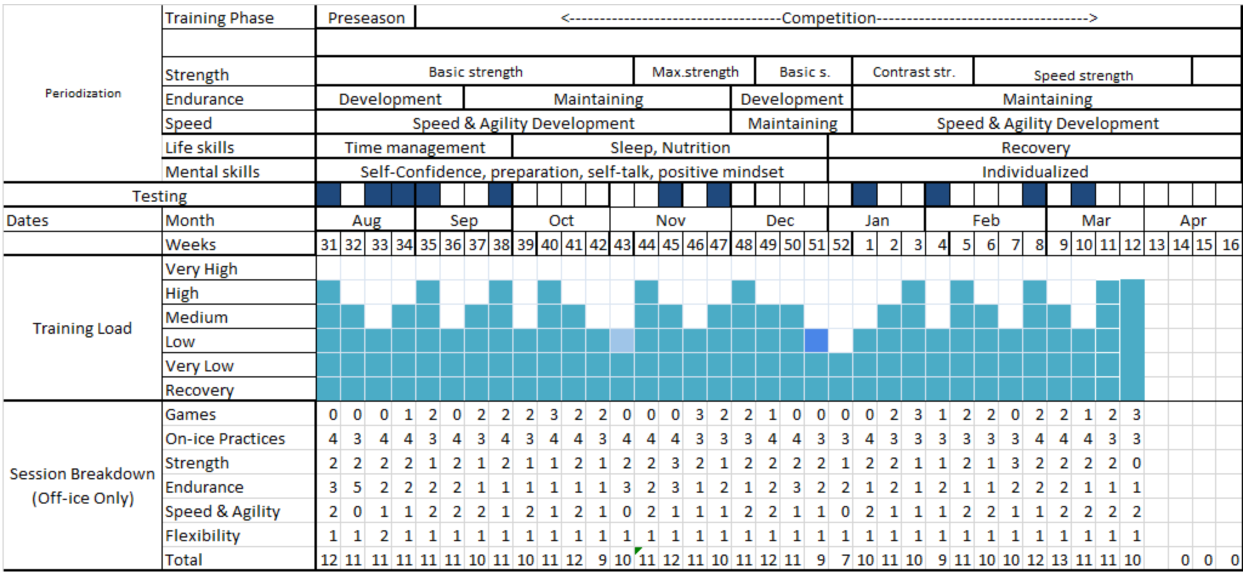

Figure 5. Season 2017-2018 summary (Oulun Kärpät Naiset 2018).

4 Measures of fitness and fatigue

The importance of managing athlete's fitness and fatigue has led to an increase of monitoring athlete loads (Thorpe et al. 2017, 2-27). When monitoring training load, the load units can be thought of as either external or internal (Halson 2014, 139-147). Traditional methods used to quantify fatigue and recovery such as maximal physical performance assessments have found to be unsuitable for the team sport environment throughout the competitive periods due to their exhaustive and time-consuming nature. The recent literature has demonstrated more simple, quick and non-exhaustive tests such as athlete self-report measures (ASRM), autonomic nervous system (ANS) response via heart rate derived indices and to a lesser extend jump protocols have been shown to be sensitive to changes in training load and serve as promising tools to quantify fatigue status. (Thorpe et al. 2017, 2-31.) No single marker or test can give a complete picture of an athlete's fitness and fatique status, so practitioners must therefore include a range of measures in their athlete monitoring programs (McGuigan 2017, 103-134).

Subjective measures, particularly measures of mood disturbance, perceived stress and recovery and symptoms of stress, have found to respond with superior sensitivity and consistency to stress imposed by training compared to objective measures (Saw et al, 2015, 281–291). As both external and internal loads have merit for understanding the athlete's training load, a combination of both may be important for training monitoring. An example of recognizing a difference between a fresh and fatigued athlete is to think of both athletes performing a same rate of physical activity. The power output for the activity may be maintained for the same duration; however, depending on the fatigue state of the athlete, this may be achieved with a high or low heart rate or a high or low perception of effort. It is this uncoupling or divergence of external and internal loads that may aid in differentiating the fatigue status. (Halson 2014, 139-147.)

4.1 External load

Traditionally, external load has been the foundation of most monitoring systems. External load refers to the work completed by the athlete, measured independently of his or her internal characteristics. (Halson 2014, 139-147.) It can be indicated as things such as weight lifted, total distance covered, and the number of sprints, impacts, and jumps performed (McGuigan 2017, 70-78). To gain an understanding of external training load, a number of technologies are available to athletes and coaches to measure power output, speed and acceleration (Halson 2014, 139-147).

In team sports, time–motion analysis (TMA), including global positioning system (GPS) tracking and movement pattern analysis via digital video (such as ProZone™) are now becoming an integral part to monitor athletes, particularly during competition (Halson 2014, 139-147). The small devices are often wristbands and can be integrated to custom software for further analysis (McGuigan 2017, 70-78). The reliability of GPS for monitoring movement is influenced by factors such as sample rate, velocity, and duration and type of task. While this approach may be time-consuming, recent data suggest that individualized speed thresholds may provide practically significant information regarding training loads. (Halson 2014, 139-147.) Currently, research comparing these devices or validating them against accepted research methods is limited, particularly in terms of their validity and reliability (McGuigan 2017, 70-78).

Measures of neuromuscular function such as the jump test (countermovement/squat jump), sprint performance, and isokinetic and isoinertial dynamometry are often utilized in the team sport environment. These assessments have become popular due to the simplicity of administration and the minimal amount of additional fatigue induced. (Halson 2014, 139-147.) Athletes can generally perform two or three jumps before a training session without any issue. Neuromuscular fatique refers to the reduction in maximal voluntary contractile force. Fatique that is often of interest to practitioners is a low -frequency fatique that is a result of high-intensity, high-force, repeated stretch-shortening cycles or eccentric (lengthening) muscle actions. (McGuigan 2017, 104-113.) Common variables from jump test measurements include mean power, peak velocity, peak force, jump height, flight time, contact time, and rate of force development. Equipment requirements for jump testing may include contact mats, portable or non-portable force platforms, and rotary encoders. (Halson 2014, 139-147.) As neuromuscular fatique is just one type of fatique in athletes, it should not be relyed alone for obtaining the full picture of athletes tracking (McGuigan 2017, 104-113).

4.2 Internal load

The internal load, or the relative physiological and psychological stress imposed is critical in determining the training load and subsequent adaptation (Halson 2014, 139-147). Monitoring internal load provides important information on how the athlete is adapting to training and is often related to athlete’s fitness outcomes. Athlete’s internal responses to the same external load can vary significantly and those should not be compared among the athletes. The internal responses are determined by a range of factors that include age, training history, physical capacity, genetics, and injury history. Measures such as heart rate and Rating of Perceived Exertion (RPE) are the most common methods of internal load, but subjectibe ratings of wellness, and blood markers and physiological methods such as lactate and VO2 are also used as internal load measures. (McGuigan 2017, 78-100.)

4.2.1 Athlete self-report measures (ASRM)

Athlete self-report measures (ASRM) are a simple and inexpensive approach to monitoring athlete's perceived physical and psychological wellbeing (Halson 2014, 139-147). In a field of sport science research and sports practise there are currently several questionnaires used (Kellmann, Kellmann et al. 2018, 10). Typically the questionnaires ask athletes about their levels of stress, muscle soreness, mood, fatique, sleep, coping and motivation (McGuigan 2017, 78-100). The most common subjective measures of athlete wellbeing were the Profile of Mood States (POMS), Recovery Stress Questionnaire for Athletes (RESTQ-S) and Daily Analyses of Life Demands of Athletes (DALDA). Other measures include i.a the overtraining questionnaire of the Societe Francaise de Medecine du Sport (SFMS), State-Trait Anxiety Inventory (STAI), Perceived Stress Scale (PSS), Multi-Component Training Distress Scale (MTDS), Competitive State Anxiety Inventory-2 (CSAI-2), Derogatis Symptom Checklist (DSC), State-Trait Personality Inventory (STPI) and a mood questionnaire by Choi and Salmon (Mood). (Saw et al, 2015, 281–291.)

Self-report measures may be characterised by: (1) whether or not they are specifically designed for athletes, (2) if they evaluate single or multiple constructs and (3) whether the constructs are based on stressors, or resulting symptoms. It has been suggested that athlete-specific measures evaluating multiple constructs may better reflect performance capacities. Broader measures may also cater to the differing circumstances and responses of individuals, capturing both training and non-training stressors and their systemic influence on subjective well-being. Therefore, on balance, the RESTQ-S and MTDS have found to be more promising self-report measures. (Saw et al. 2015, 281–291.)

In a sport environment, the practitioners often use their own modified questionnaires because the published ones lack sport specificity, have too many items and thus take too much time to compelete and analyze. The questionnaires that cover a wide range of self-report measures but ask a smaller number of questions are ideal. The most useful measures appear to be perceived muscle soreness, fatique, wellness, and sleep duration and quality. Measures can be collected on a regular basis, even daily, and it is important that the wellness measures be taken at the same time of day. However, the daily questionnaires and the same questions every day might lead to questionnaire fatique and lower the response rate. Well designed questionnaires should result in quality information without overloading either athletes or practitioners. The reverse side of the custom-designed questionnaires is the lack of research and the effectiveness of the questionnaires might be uncertain. Ultimately, practitioners need to consider the design of the questionnaire and the factors that could influence the data. (McGuigan 2017, 90-99.)

4.2.2 RESTQ-S and MTDS

Recovery Stress Questionnaire for Athletes (RESTQ-S), which provides a measure of perceived stress and recovery in athletes is one of the most widely used questionnaires in athlete monitoring (McGuigan 2017, 95-97). It has found to be the only investigated self-report measure to be responsive to both acute and chronic training load (Saw et al. 2015, 281–291). The original RESTQ-S comprises 76 questions divided into 19 scales: 7 scales relate to general stress, 5 relate to general recovery, 3 relate to stress in sport, and 4 relate to specific recovery in sport. It is probably more suitable for weekly applications as the time required to complete the questions have gained a lot of concerns. The short RESTQ-S has 32 questions and has been developed with eight items covering physical performance capability, mental performance capability, emotional balance, overall recovery, muscular stress, lack of activation, negative emotional state, and overall stress. The validity of both of these questionnaires has been confirmed in the literature. (McGuigan 2017, 96.)

Multicomponent Training Distress Scale (MTDS) assesses training-related distress and readiness to perform. It is a short 22 question scale that includes mood disturbance, stress, and behavioral subscales and it assess distress symptoms such as sleep disturbance, general fatique, changes in appetite, difficulties with concentration and physical discomfort. The questionnaire is rated in 5-point scale and the athletes rate their experinced symptoms in the previous 24 hours. (McGuigan 2017, 91-92.)

4.2.3 Session rating of perceived exertion

Foster et al. developed the session RPE method of quantifying training load, which involves multiplying the athlete’s RPE (on a 1–10 scale) by the duration of the session (in minutes) (Halson 2014, 139-147). These session load values are used to calculate two other important variables, training strain and training monotony (Comyns T.& Flanagan EP. 2013, 78-85). The session RPE scale differs from the Borg’s category ratio 10 (CR-10) scale in number range and verbal descriptors. It asks the athlete, ”how was your workout?” and is scaled as follows: 0 = rest, 1 = very easy, 2 = easy, 3 = moderate, 4 = somewhat hard, 5-6 = hard, 7-9 = very hard, and 10 = maximal. This simple method is arguably the most widely used monitoring tool in high-performance sport. (McGuigan 2017, 78-80.)

The session RPE method has been shown to be noninvasive, valid and reliable method to assess training load in steady-state aerobic training, intermittent-aerobic training, and strength training. The validity of the method has been specifically investigated in training sessions for collision-based field sports. (Comyns& Flanagan 2013, 78-85.) The method was developed to eliminate the need to utilize HR monitors or other methods of assessing exercise intensity. While the session RPE method may be simple, valid, and reliable, the addition of HR monitoring may aid in understanding some of the variance that it does not explain. (Halson 2014, 139-147.)

4.3 Heart rate variability and Heart rate recovery

Physiological markers such as heart rate recovery and heart rate variability can be used as objective markers of fatique (McGuigan 2017, 113-116). Monitoring HR is one of the most common means of assessing internal load in athletes (Halson 2014, 139-147). HRV is a measure of the normal variability in beat-to-beat intervals and it can be determined using several indices, in which one of the most reliable is the natural logarithm of the square root of the mean sum of squared differences between adjacent normal RR intervals (Ln rMSSD). Heart rate variability (HRV) is widely used in both individual and team sports to provide an insight into an athlete’s training readiness. (McGuigan 2017, 113-116.) The measurement of resting or post-exercise HR variability (HRV) has been suggested to indicate both positive and negative adaptations to training (Halson 2014, 139-147).

Low resting HR and high HRV are generally related to high level of endurance performance (Nummela et al, 2017, 7). This is not always the fact since pathological conditions can produce HRV. An optimal level of HRV is associated with health and self-regulatory capacity, adaptability and resilience. (Shaffer& Ginsberg 2017, 258.) Factors such as stress can lead to the withdrawal of parasympathetic activity, or activation of sympathetic branch even when a person is resting. Both above-mentioned activities leading to elevated heart rate and lowered HRV. (OuraHealth, 2018.)

However, the varying methodological approaches employed, as well as high day-to-day variability in environmental and homeostatic factors, have resulted in inconsistent findings in the scientific literature. As such, HRV has been shown to increase without a change in fitness (VO_{2max}) as well as decrease alongside increases in fitness. Increases, decreases, and no change in HRV have also been reported in the over-training literature. (Halson 2014, 139-147.) Heart rate variability should not be compared with other people, because there are a numerous factors affecting HRV, such as age, hormones and the overall body functions, as well as lifestyle. A person's HRV values can be compared to their own values if they are tracked with the same method and in similar conditions. (OuraHealth, 2018.)

To overcome some of the inconsistencies in findings, it has been suggested that both weekly and 7-day rolling averages have higher validity than single-day measurements. While various HRV indices can be measured, the use of the natural logarithm of the square root of the mean sum of the squared differences between R–R intervals (Ln rMSSD) has been found to be the most reliable. This is due to the lower co-efficient of variation compared with other indices, a lack of influence of breathing frequency, and that data can be collected over a short period of time and easily calculated. As is the case with the majority of tools to monitor elite athletes, longitudinal monitoring and an understanding of individual responses in HRV to training, taper and competition is critical. (Halson 2014, 139-147.)

HR recovery (HRR) is the rate at which HR declines at the cessation of exercise and has been suggested to be a marker of autonomic function and training status in athletes. HRR is characterized by opposing autonomic nervous system activity, with an increase in parasympathetic activity and withdrawal of sympathetic nervous activity athletes. In a recent review on HRR and monitoring changes in training status, it is suggested that HRR improves with increased training status, remains unchanged when there is no change in training status, and decreases when training status is reduced. (Halson 2014, 139-147.) Decrements in HRR have been suggested as an indicator of fatique, detraining, or an inability to cope with the assigned training load and on the contrary, improvements in HRR can be an indicator of enhanced fitness (McGuigan 2017, 114-115). However, the considerations such as hydration, environment and medication may influence HR and HRR (Halson 2014, 139-147).

Measures of heart rate in submaximal exercise protocols can provide useful insights for athlete monitoring. Heart rate recovery and heart rate variability can both be used to monitor fitness and fatigue in athletes. (McGuigan 2017, 113.) Previous studies suggest that changes in HR and HRV during night sleep seems to provide useful information about acute and cumulated training load (Nummela et al, 2017, 7). These analyzes can be a good tool to support other tracking, but the training loads should not be planned based on these messages alone. Scientific evidence of the reliability of heart rate and heart rate-based programs in monitoring training loads does not yet exist. (Uusitalo 2015, 2344-50.)

5 The impact of Sleep on recovery

Sleep is considered a re-occurring behavioural state, in which movement and responsiveness are reduced. The function of sleep is still largely unanswered and there is no clear consensus existing among the evidence. It has been proposed that sleep affects growth, development of brain and nervous system and supports anabolism. Another study proposed that sleep is important for somatic function and the replenishment of cerebral glycogen stores (1981), while recent study in 2013 shows the importance of sleep for memory consolidation. Furthermore, sleep serves multiple functions that influences most of our molecular, cellular, physiological and neurological functions. (Kellmann, Kellmann et al. 2018, 151-163.)

Adequate sleep is distinguished by suitable sleep routine, ample duration, high efficiency and quality. For adults the recommended sleep per night is seven to nine hours, (Kellmann, Kellmann et al. 2018, 151-153) but elite level athletes with increased levels of stress (training and other life demands) need even more sleep to overcome the daily stressors and optimize the recovery (Underwood J, 2-24).

5.1 Role of sleep in performance

Physical and mental performance have now been directly linked to sleep or a lack of sleep (Underwood, 2-24). Sleep is often suggested to be the single best recovery strategy available for elite level athletes (Hausswirth& Mujika 2013, 99-110). The recent studies show that the brain and central nervous system (CNS) play the most significant role in optimal performance, and that sufficent sleep is the most important thing for those systems to function (Underwood, 2-24).

There are many factors leading to compromised sleep in athletes. The most common circumstances in sleep disturbances faced by the elite level athletes are early morning trainings, nighttime competitions, electronic devices used prior to bed, long haul travels and use of stimulating ercogenic aids in the evening. (Kellmann, Kellmann et al. 2018, 154-156.) Athletes may also experience disruption of sleep patterns, partial sleep loss, or complete overnight sleep deprivation due to psychological stress and anxiety. A consumption of alcohol has also a negative effect on sleep quality. Moderate alcohol consumption 30 to 60 minutes before bed time may result in sleep disturbances. Research findings demonstrate that alcohol consumption may affect both the quality and quantity of sleep in athletes. (Hausswirth& Mujika 2013, 99-108.)

The recent literature suggests sleep disruption or deprivation can negatively affect exercise performance or capacity. Differences in findings relating to exercise performance have been associated with various physiological and metabolic disturbances and negative effects on perceived exertion and mood states, for example irritability and mental fatique. (Hausswirth& Mujika 2013, 99-108.) Sleep loss can affect numerous elements relating to performance, including physical output, decision making and the potential for injury and illness (Kellmann, Kellmann et al. 2018, 163). Halson (2014, 139-147) regards the effects of sleep loss or deprivation to motivation, perception of effort and cognition as well as numerous other biological functions. Minimal sleep can decrease glucose metabolism which fuels the brain and the body, and decrease the amount of testosterone, which allows athlete to build and rebuild muscles and gain training effect from different workouts. Further, adequate sleep allows organs to rest and recover, sort out daily information and download critical movement patterns to brain circuitry and catalogs them in movement and premovement sectors of the brain. (Underwood, 2-24.)

Particular attention should be given to appropriate strategies for improving sleep quality in athletes in order to optimize physiological adaptations for enhancing performance and maintaining health and wellbeing. The strategies refer mainly to training schedule, stress management, nutrition and hydration. (Hausswirth& Mujika 2013, 99-108.) It has been proposed that consistent sleeping pattern, optimizing the temperature of bedroom, avoiding heavy meals close to bedtime and de-stressing may have impact in improving sleep quality and quantity (OuraHealth, 2018).

5.2 Sleep & monitoring sleep

Sleep can be divided in two distinct states, rapid eye movement sleep (REM) and non-rapid eye movement sleep (NREM) (Kellmann, Kellmann et al. 2018, 152). These two states alternate intermittently in approximately 90-minute cycles throughout the night (OuraHealth, 2018). REM sleep is characteristically defined by electroencephalogram (EEG) activation (Carskadon& Dement 2011, 16-26), rapid eye movements, vivid dreams and suppressed skeletal muscle tone (Kellmann, Kellmann et al. 2018, 152). During REM sleep, the body repairs its tissues and cells and begins to reboot CNS energy and function (Underwood, 2-24). This sleep stage is associated with memory consolidation, learning and creativity (OuraHealth, 2018). In a period of 8 hours of sleep, REM sleep comprises 1.5 to 2.5 hours of total sleeping time (Underwood, 2-24), but the amount of REM can vary significantly between nights and individuals (OuraHealth 2018). Less than 20% of REM sleep in a night is related to questionable recovery and performance (Underwood, 2-24).

The other sleep state NREM is subdivided into three different stages (N1, N2, N3) related to the depth of sleep (Kellmann, Kellmann et al. 2018, 152). The stages roughly parallel a depth of sleep continuum, with arousal thresholds generally lowest in stage N1 and highest in stage N3 (Carskadon& Dement 2011, 16-26). Stage N3 is often referred to as deep sleep or slow-wave sleep (SWS) (Kellmann, Kellmann et al. 2018, 152).
The electroencephalogram (EEG) pattern in NREM sleep is commonly described as synchronous, with such characteristic waveforms including K-complexes, sleep spindles and high voltage slow waves). NREM is associated with low muscle tonus and minimal psychological activity. (Carskadon& Dement 2011, 16-26.)

Sleep usually begins with light sleep, that consist N1 and N2 sleep, which are the first two stages of NREM sleep. N1 is a very light sleep between sleep and wakefulness and N2 is a deeper state that prepares a body for transitions between sleep states. Light sleep makes up about 50% of total sleeping time in adults. Deep sleep, N3 or slow-wave sleep (SWS) is the most restorative and rejuvenating sleep stage, enabling muscle growth and repair. (OuraHealth, 2018.) SWS is characterised by the presence of high-voltage, slow-frequency brain waves, slow heart and respiratory rates and low cerebral blood flow. During periods of SWS, the release of growth hormone appears and stress hormone cortisol suppress, creating ideal conditions for anabolism. It is proposed that SWS is important for recovery in athletes. (Kellmann, Kellmann et al. 2018, 152-153.) The amount of deep sleep can vary between nights and individuals, but the average time spend in deep sleep is 15-20% (1-1.5h) of total sleeping time (OuraHealth, 2018).

Monitoring sleep quality and quantity can be useful for early detection and intervention before significant performance and health decrements are observed (Halson 2014, 139-147). The sleep monitoring in athletes has been mostly obtained using subjective questionnaires, wrist actigraphy or the gold standard polysomnography. The use of the latter has limitations in its time consuming and labour demanding nature. The methods such as sleep questionnaires and wrist or finger artigraphys offer a non-invasive and inexpensive means to assess sleep quality and quantity in athletes. (Kellmann, Kellmann et al. 2018, 153-154.) The use of an actigraphy can provide data on bedtime, wake time, sleep-onset latency (time taken to fall asleep), wake during sleep, and sleep efficiency (estimate of sleep quality), as well as provide information on sleep routines. Due to the increasing knowledge regarding the importance of sleep, sleep monitoring and assessment is becoming popular with elite athletes, coaches, and support staff. (Halson 2014, 139-147.)

6 The aims and research questions

The aim of this study was to test the hypothesis of relationship between training load, perceived ratings of wellness and Oura ring data. Does the increases in training load show increases in Resting Heart Rate and decreases in Heart Rate Variability? Does the wellness-assessment correlate with the Oura data and is there relationship between the different Oura ring variables? Is there a lot of individual differences in the results between the players? Is training load associated with perceived ratings of wellness?

1. Are acute and chronic training load associated with RHR and HRV?
2. Is there a relationship between wellness-assessment and RHR and HRV?
3. Does the ring data, containing RHR, average RHR and HRV correlate?
4. How remarkable are the individual differences?
5. Is there a relationship between training load and wellness-assessment?

7 Research methods

7.1 Purpose of the study

A Finnish company Oura Health, the manufacturer of the smallest wearable ring in the market offered the team Oulun Kärpät Naiset a possibility to take part in a validity research to assess the functionality of the Oura ring in a use of female elite athletes. The Finnish Women's hockey league is raising its level year by year and it forces the teams to improve their activities to enhance both training and recovery of the athletes. The purpose of the study was to find out if Oura ring could be used as a monitoring tool to guide and optimize the players individual recovery during the season.

Another objective was to collect reliable data of the players individual training load for the use of Oura Health company for future development of the product. The company also required exact information of the alcohol consumption (time and amount of alcohol doses) and information of possible injuries/illnesses. The Oura Health company requires the data from the study to build and authenticate algorithms of the ring. Oura Health is also looking for concretical examples of how the training load, consumption of alcohol and possible illnesses/injuries affects the Oura ring data. In future this could help the coaches to regulate the training load due to the information given from the ring

7.2 Subjects

The subjects of the study were ice hockey players from Oulun Kärpät Naiset team playing in the Finnish Women's National league. Nineteen (19) players of the team with an average age of 22,1 years participated in this study. None of the players are fully professional, meaning most of them either study or work together with their playing career. Most of the players study, six in University, five in University of Applied Sciences, four in college/vocational school and four of them working in full-, or part-time jobs. Two of the team's players have earned an athlete's grant from the Olympic Committee of Finland.
Backround information is presented in table 1.

19 players	Average	Maximum	Minimum
Age (years)	22,1	35	16
Height (cm)	165,7	173	147
Weight (kg)	67,5	87	61

Table 1. Subjects personal details

7.3 Study design / Procedure

The aim of the study was to collect data of the training load of the team players and their wellness- assessment of the overall recovery. The daily self-assessment average and the nightly Oura data were then compared to the previous day training load, acute training load (4 days) and chronic training load (2 weeks) and seen if there are association in the data between these different methods. The parameters used by the Oura ring were the nightly average Heart Rate Variability (HRV), lowest Resting Heart Rate (RHR) and average Resting Heart Rate.

With the amount of data from different monitoring systems, the Oura ring, the wellness questionnaire and the training diary with ratings of perceived exertion comes the requirement to intercorporate this information into a data-management system that results in meaningful information. This was done by using a correlation analysis with the help of a senior lecturers from Haaga-Helia UAS expertised in stress and recovery monitoring and data management. In this study the analysis was done with the the data from 28th of September to 8th of November.

In the end of the research all the collected data and the training diaries will be given to Oura Health as an anonymous package. Oura Health will use the information for their future research and development. The players could resign from the research at any time and cancel the permission for their data with no argumentation.

7.4 Data collection

The subject group players were given an Oura wellness ring for a four (4) months period starting on August 2018. The players could use the ring independently and get daily data of their sleep and recovery. This was the time when the Oura Cloud was collecting the players individual baseline data for more accurate Oura analysis. Before the research the players signed a data protection, a permission that their individual data can be collected and analyzed from the Oura Cloud by the authorized persons including the coaching staff, researchers and the author of the thesis.

From September 2018 the players were asked to fill out a training diary with the perceived ratings of exertion and a questionnaire of their perceived ratings of wellness for eight weeks period. Players were also asked to inform all alcohol consumption and possible injuries and illnesses during the study to the author of the thesis, for future research of Oura Health. During the research there was a one-night echocardiogram (ECG) measuring for all the players with a Bittium Faros ECG device. This was done to record the electrical activity of the heart and to get data from a medical device to validate the data from Oura ring.

7.5 Measurement of readiness/ recovery

The measurement of the players readiness and recovery status was studied with three different monitoring systems for eight weeks period. The players were given the Oura ring for everyday use, they were asked to fill out a wellness questionnaire every morning and a training diary every evening. From the Oura Cloud the coaches, the researchers and the players could see the Oura data in a daily basis. The data from the wellness questionnaire was resolved in a weekly basis and the team averages were reported to the head of coaching. The sustained perceived negative states of wellnesses were regarded and discussed personally with the players. The daily data from Oura and the answers from the wellness questionnaire were used to modify and individualize the players training.

7.5.1 Oura analysis

The Oura ring is the smallest wearable manufactured, measuring the body signals from the finger. It is designed to be worn around the clock to track sleep, recovery and activity. It has advanced sensors, it is water resistant, durable and has a long battery life up to one week. Oura ring measures the body signal data with three types of sensors. The signals that Oura ring processes are: Interbeat interval (IBI), pulse amplitude variation, ECG level resting heart rate (RHR), heart rate variability (HRV), respiratory rate, movements, intensity of physical activity and body temperature deviation. Before the tracking can be started, the Oura application needs some personal informations for the analyzing of the data such as the age, height, weight and gender. The ring is not recommended to use during contact sports, but the training activities (time, activity type, duration and intensity) can be added to Oura Cloud after the workout is done. (OuraHealth, 2018.)

Heart rate (HR), heart rate variability (HRV) and respiratory rate is derived by the Infrared LEDs that access blood volume pulse (BVP) from the palmar arteries of the finger. The ring detects the pulse waveform and amplitude variation and exact time between heartbeats for example interbeat interval (IBI). There are different ways to calculate HRV, but they all have to do with the amount of variation in the intervals between heartbeats. Oura utilizes rMSSD (Root Mean Square of the Successive Differences), which is the most commonly used HRV formula. Figure 6 is an example of interbeat intervals in milliseconds. (OuraHealth, 2018.)

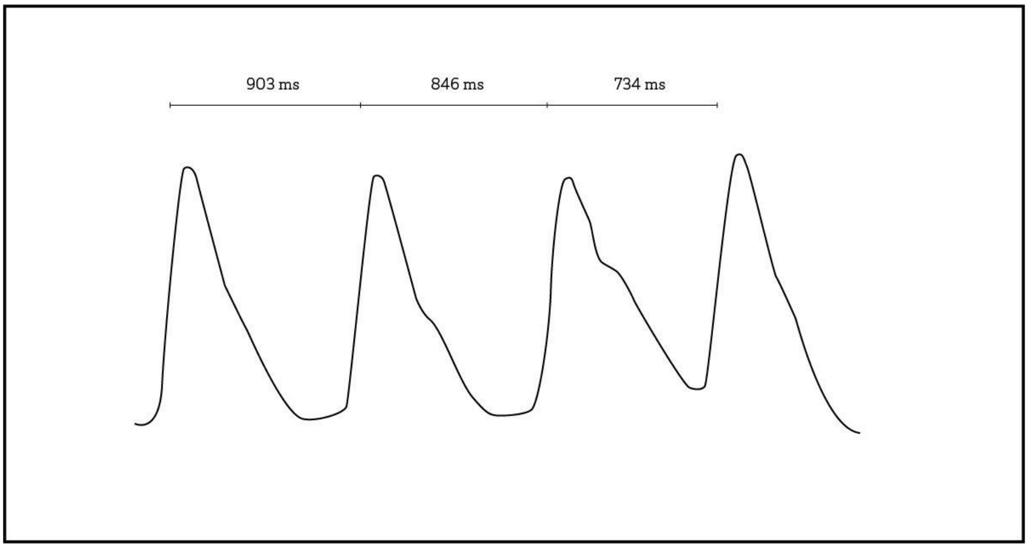

Figure 6. An example of interbeat intervals in milliseconds (OuraHealth, 2018).

Body movements, amplitude and intensity of the movements is tracked by gyroscope and 3D accelerometer that captures samples at the rate of 50 Hz. The NCT body temperature sensor tracks the temperature every minute during sleep and detects when the skin temperature corresponds the body temperature. By comparing that value from earlier nights, it indicates the body temperature baseline and any variations of it. (OuraHealth, 2018.)

Oura ring analyses the data and provides a daily compilation of the measurements in three different categories scaled from 1 to 100. The categories are Readiness, Sleep and Activity. The readiness score is calculated from contributors which are previous night, sleep balance, previous day activity, activity balance, body temperature, resting heart rate and recovery index. The Sleep score comes from the contributors: total sleep time, efficiency, tranquillity, rem sleep, deep sleep, latency (the time to fall asleep), and timing. Activity score is calculated from contributors: stay active, move every hour, meet daily targets, training frequency, training volume and recovery time. (OuraHealth 2018.) Figure 7 shows an example of nightly RHR and HRV (OuraCloud 2019).

Figure 7. Example picture of nightly Resting Heart Rate and Heart Rate Variability (OuraCloud 2019).

7.5.2 Wellness-assessment

The psychometric questionnaire was used to assess general indicators of player wellness every morning for eight weeks. The morning questionnaire had three questions relating to perceived overall fatique, quality of sleep and delayed-onset muscle soreness (DOMS). As Oura ring measures the sleep duration, it was not added as part of the questionnaire. Each question was scored on a five-point scale (1-5), where 1 was representing very poor (negative state of wellness) and 5 representing very good (positive state of wellness). The questions of the wellness questionnaire were adopted from the study of Thorpe et al. (2016). The questionnaire was executed online via Webropol surveys. In the final data analysis, the wellness questionnaire was analysed as a sum of these three questions.

As most of the subject players either study or work during the daytime, the overall load including life load, training load etc. is quite high. That is why the wellness questionnaire was short and easy to implement in daily routines. It has been presented (McGuigan 2017, 98-99) that the most useful measures to assess wellness appear to be perceived muscle soreness, fatique, wellness, and sleep duration and quality, and that ideal questionnaires cover a wide range of self-report measures with only a small number of questions.

7.5.3 Training load assessment/ training diary

Players training diaries and perceived ratings of exertion were monitored online via Webropol surveys. Rating of Perceived Exertion (RPE) was chosen, because it is one of the most common ways of internal load. (McGuigan 2017, 78-100.) The players filled their daily training or game session duration, content of each session, time of the session and rating of perceived exertion (RPE) every evening. (McGuigan 2017, 190.) These variables were used to calculate the players individual training load by multiplying the athlete's RPE (on a 1–10 scale) by the duration of the session (in minutes) (Halson 2014, 139-147). These session load values can also be used to calculate two other important variables, training strain and training monotony (Comyns& Flanagan 2013, 78-85). The session RPE was asked to fill up within 20 to 30 minutes after each training session. During the study there were players that moved to manual version instead of online questionnaire and used a paper version of the training load assessment.

7.6 Statistical methods

All the collected data from the training load, the wellness questionnaire and the Oura were brought together in excel and The Pearson correlation analysis was used to examine the relationship between the variables.

The Pearson correlation coefficient is measure of a linear association between two variables and is denoted by *r*. The strength and direction of correlation is computed into correlation coefficient which ranges between -1 and +1. (Figure 9). A value of 0 indicates that there is no relationship between the two variables. A value greater than 0 indicates a positive relationship and a value less than 0 indicates a negative relationship. The stronger the relationship between two variables, the closer the Pearson correlation coefficient *r,* will be to either +1 or -1. The results can be interpreted by following guidelines. (Statistics.laerd 2019.)

	Coefficient, *r*	
Strength of Association	Positive	Negative
Small	0.1 to 0.3	-0.1 to -0.3
Medium	0.3 to 0.5	-0.3 to -0.5
Large	0.5 to 1.0	-0.5 to -1.0

Figure 8. Coefficient of correlation (Statistics.laerd 2019).

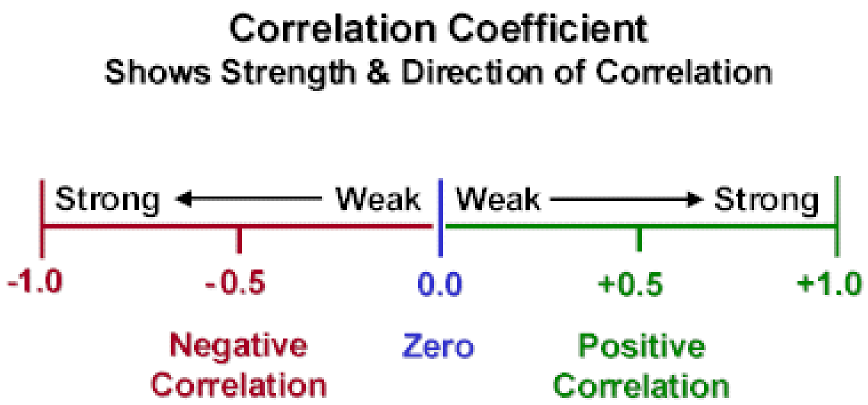

Figure 9. Shows Strength and Coefficient of Correlation (Researchgate 2019).

8 Results

This section is going to review the results for each factor separately. First of all, the coefficient of correlation that indicates the strength and direction of the relationship between the variables has to be found. Secondly, the significance of the relationship needs to be identified. The collected data was analysed from six weeks period from 28th of September to 8th of November.

8.1 Relationship between training load and Oura ring data

In a full data, the daily training load percentage or the acute training load did not show significant correlation with the Oura ring data. There is also no significant correlation between chronic training load and the Oura data. The values range between 0,02- 0,07. This analysis proved that the variation in training load did not have relationship with Oura ring data when examining the full data. Table 2. shows the relationship between training load and Oura ring data.

Full data	Training load %		
Training load %	r=1,00	n=799	
Acute training load 4 days	r=,47	n=742	p=,000
Chronic training load 2weeks	r=,23	n=742	p=,000
Sum of wellness	r=,17	n=798	p=,000
Min HR	r=-,04	n=663	p=,291
Mean HR	r=-,02	n=663	p=,598
HRV	r=,07	n=662	p=,081
	Acute training load 4 days		
Training load %			
Acute training load 4 days	r=1,00	n=743	
Chronic training load 2weeks	r=,67	n=743	p=,000
Sum of wellness	r=,18	n=742	p=,000
Min HR	r=-,03	n=664	p=,465
Mean HR	r=-,02	n=664	p=,608
HRV	r=,07	n=663	p=,083
	Chronic training load 2weeks		
Training load %			
Acute training load 4 days			
Chronic training load 2weeks	r=1,00	n=743	
Sum of wellness	r=,17	n=742	p=,000
Min HR	r=,04	n=664	p=,353
Mean HR	r=,03	n=664	p=,422
HRV	r=-,03	n=663	p=,412

Table 2. Correlation analysis of training load percentage, acute-, and chronic training load.

8.2 Relationship between wellness-assessment and Oura ring data

The analysis shows no significant correlation between the wellness-assessment and Oura ring variables in a full data. The values range between 0,01-0,04. This meaning that the Sum of wellness (perceived overall fatique, quality of sleep and delayed-onset muscle soreness) did not have relationship with the Oura variables. Table 3. shows the relationship between the wellness-assessment and Oura ring data.

Full data	Sum of wellness		
Training load %			
Acute training load 4 days			
Chronic training load 2weeks			
Sum of wellness	r=1,00	n=799	
Min HR	r=-,01	n=664	p=,704
Mean HR	r=-,01	n=664	p=,836
HRV	r=-,04	n=663	p=,279

Table 3. Correlation analysis of wellness-assessment.

8.3 Relationship between Oura ring variables

All the variables show strong relationship between each other. The analysis shows strong positive correlation (0,94) between lowest Resting Heart Rate and average Resting Heart Rate. The correlation between the Heart Rate Variability and lowest RHR shows strong negative correlation (-0,6) and strong negative correlation (-0,54) between average RHR. This means that increases in Resting Heart Rate have decreasing effect on Heart Rate Variability. Table 4. shows the relationship between the Oura ring variables.

	Min HR		
Min HR	r=1,00	n=664	
Mean HR	r=,94	n=664	p=,000
HRV	r=-,60	n=663	p=,000
	Mean HR		
Min HR			
Mean HR	r=1,00	n=664	
HRV	r=-,54	n=663	p=,000

Table 4. Correlation analysis of Oura ring variables.

8.4 Individual players and their data

There are a lot of differences between the individual players data. For example, the effect of acute training load on lowest Resting Heart Rate varies between weak negative correlation (-0,32) to strong positive correlation (0,73). The effect of chronic training load on Heart Rate Variability varies between strong negative correlation (-0,71) to strong positive correlation (0,57). Some players in the study had remarkable strong correlation in most of the parameters, but some players did not have any correlation at all, and the individual results varied a lot. The most accurate parameter of the Oura ring variables seems to be the nightly Heart Rate Variation. Table 5. and 6. show examples of players with strong correlation parameters in their data.

Player 21		
	Kuormaprosentti %	Acute training load 4 days
Training load %	r=1,00 n=44	
Acute training load 4 days	r=,65 n=41 p=,000	r=1,00 n=41
Chronic training load 2w.	r=,60 n=41 p=,000	r=,87 n=41 p=,000
Sum of wellness	r=,33 n=43 p=,029	r=,42 n=40 p=,007
Min HR	r=,58 n=29 p=,001	r=,73 n=29 p=,000
Mean HR	r=,66 n=29 p=,000	r=,79 n=29 p=,000
HRV	r=-,54 n=29 p=,002	r=-,68 n=29 p=,000
	Chronic training load 2w.	Sum of wellness
Sum of wellness	r=,21 n=40 p=,191	r=1,00 n=43
Min HR	r=,73 n=29 p=,000	r=,22 n=29 p=,251
Mean HR	r=,76 n=29 p=,000	r=,29 n=29 p=,121
HRV	r=-,71 n=29 p=,000	r=-,18 n=29 p=,337
	Min HR	Mean HR
Min HR	r=1,00 n=29	
Mean HR	r=,96 n=29 p=,000	r=1,00 n=29
HRV	r=-,78 n=29 p=,000	r=-,81 n=29 p=,000

Table 5. Correlation analysis of player 21.

Player 1		
	Training load %	Acute training load 4 days
Training load %	r=1,00 n=42	
Acute training load 4 days	r=,45 n=39 p=,004	r=1,00 n=39
Cronic training load 2w.	r=,19 n=39 p=,240	r=,48 n=39 p=,002
Sum of wellness	r=,07 n=42 p=,638	r=,08 n=39 p=,644
Min HR	r=-,08 n=37 p=,651	r=-,26 n=37 p=,124
Mean HR	r=-,16 n=37 p=,335	r=-,24 n=37 p=,160
HRV	r=,21 n=37 p=,218	r=,40 n=37 p=,014
	Chronic training load 2w.	Sum of wellness
Sum of wellness	r=-,21 n=39 p=,208	r=1,00 n=42
Min HR	r=-,63 n=37 p=,000	r=,22 n=37 p=,198
Mean HR	r=-,55 n=37 p=,000	r=,08 n=37 p=,637
HRV	r=,57 n=37 p=,000	r=,02 n=37 p=,921
	Min HR	Mean HR
Min HR	r=1,00 n=37	
Mean HR	r=,89 n=37 p=,000	r=1,00 n=37
HRV	r=-,88 n=37 p=,000	r=-,90 n=37 p=,000

Table 6. Correlation analysis of player 1.

8.5 Relationship between training load and wellness-assessment

In the full data the effect of training load shows low significant correlation on wellness- assessment. All the training load parameters including training load percentage, acute training load and chronic training load show low positive correlation (0,17-0,18). Table 7. show the relationship between training load and wellness- assessment.

Full data	Training load %		
Training load %	r=1,00	n=799	
Acute training load 4 days	r=,47	n=742	p=,000
Chronic training load 2weeks	r=,23	n=742	p=,000
Sum of wellness	r=,17	n=798	p=,000
	Acute training load 4 days		
Training load %			
Acute training load 4 days	r=1,00	n=743	
Chronic training load 2weeks	r=,67	n=743	p=,000
Sum of wellness	r=,18	n=742	p=,000
	Chronic training load 2weeks		
Training load %			
Acute training load 4 days			
Chronic training load 2weeks	r=1,00	n=743	
Sum of wellness	r=,17	n=742	p=,000

Table 7. Relationship between training load and wellness- assessment.

9 Discussion

This study examined if Oura ring can be used as a tool for monitoring stress and recovery for elite female ice hockey players. The application of such monitoring tools is nowadays strongly recommended for sports, if they can provide reliable and valid information (Kellmann, Kellmann et al. 2018, 261). The study was conducted by comparing the ring data with training load and wellness-assessment by using a correlation analysis. After collecting all the data, there was a part when all the information was brought up together in excel and the correlation analysis was executed.

The analysis showed a wide individual variety in the results, but the main findings were that either the acute training load or the chronic training load did not associate with the data of Oura ring when examining the full data. Neither did the wellness-assessment of players perceived wellbeing have relationship with the ring data in general. However, the full data showed strong correlation when examining the different Oura variables and in addition, the individual results showed medium to strong relationships in both effect of training load and subjective wellness- assessment on the ring variables. Referring to previous studies (Thorpe et al. 2017, 2-32), these results support the fact, that athlete monitoring should always be examined individually, as fatigue experienced by team-sport athletes is multifactorial in nature and the athletes respond to training may vary signifigantly. To overcome some of the inconsistencies in findings, some studies (Halson 2014, 139-147) suggested that when examining heart rate variability, both weekly and 7-day rolling averages have higher validity than single-day measurements which were used in this study.

As Oura ring collects the data during the day and night it is important for the individual to wear the ring continuously. If the player does not wear the ring during the training, it is possible to add the activity to the Oura Cloud afterwards. If not, it affects the readiness score and gives a measuring error in a total data. This was a reason why this study was conducted by using parameters as the nightly HRV and RHR rather than the daily readiness score. Another limitation was that when the players used the ring on ice, the ring couldn't measure all the skating as accurately as it measures the activity when a person is walking or running. This affects the readiness data on Oura Cloud, if the player does not fill the activity manually.

9.1 Effect of training load on RHR and HRV

The acute or the chronic training load did not correlate with the data from Oura ring in general. There is a possibility for some measurement errors during the study and differences in how the individual player experiences the training load. There are many factors such as age, hormones and the overall body functions, as well as lifestyle that affect Heart Rate Variation and Resting Heart Rate (Halson 2014, 139-147) and this might be the reason that the full data did not show relationship. This study does not consider the stress caused by the other life stressors than the training load for example. Measures of the stressors outside the sport should be considered in future studies. Most of the studies have been focused on male participants, so this might also reflect the results when studying female participants. One limitation in the results comes from the the use of alcohol or any medication, which were not excluded from the correlation data, and this may have affected the general data. (Table 2.)

Because of the distinct roles on ice and divergent off ice training there are a lot of individual differences in how the players practice and this has a huge role in HRV. It is likely that heart rate variability will better reflect the load caused by endurance type exercise than neuromuscular fatique caused by strength training, but the effects of more intensive training have not been studied enough. (Kaikkonen 2017, 30-33.)

9.2 Wellness-assessment and its relationship to RHR and HRV

The subjective wellness-assessment did not have association with the data from Oura in general. As it is studied earlier (Saw et al. 2015, 281–291), subjective measures reflected acute and chronic training loads with superior sensitivity and consistency comparing to objective measures. The wellness-assessment questionnaire was disapproved by some of the players in the beginning, as they felt that the answers did not respond their feelings. This was discussed through with the team and the idea of the questionnaire was explained better for the players. This argumentation helps with compliance to the observing and improves the quality of the monitoring data (McGuigan 2017, 200-201). After that the players approved the idea and the response rates were high. (Table 3.)

In future these questionnaires could be more individualized to meet the individual responses, but the question is, if it is possible timewise in a team sports like ice hockey. The reverse side of the custom-designed questionnaires is the lack of research and the effectiveness of the questionnaires might be uncertain. The well designed questionnaire should result in quality information without overloading either players or the coaches. (McGuigan 2017, 90-99.)

9.3 Association between the Oura ring variables

The correlation analysis shows strong association with all the Oura ring variables consisting Heart Rate Variability, lowest Resting Heart Rate and average Resting Heart Rate. This indicates the reliability of the measurements on autonomic regulation, as all the different variables show significant correlation. The autonomic regulation produces increases in RHR (sympathetic response) and have decreasing effect on HRV (parasympathetic response) and the other way around (Nummela et al, 2017, 7-14). (Table 4.)

9.4 Differences between results of the individual players

The individual players had a wide variety in the results. There were many players that had significant correlations in between training load and Oura variables, and between wellness-assessment and Oura variables, while some of the players datas had no correlation at all. There can be a lot of reasons explaining the variety between the results as it is evaluated in the earlier chapter 9.1. One of the most interesting result was the difference of the players recovery during away games. Some of the players got for example more sleep during the away games than what they got during the regular weeks or during home games. This gives an idea how much the players experience stress outside of the sport, and how many players lack sufficient sleep and recovery during their regular training weeks, because of their work and studies.

The study was quite a long process for the players, and it took time and will to carefully fill up the necessary information daily for eight weeks period. The individual interests for the recovery monitoring varied a lot and some of the players gave up for the process during the study and their data was excluded from the research. From 26 players that started the process in the beginning, there were 19 players that finished. There were some technical issues with the rings that affected a few participants, and some got injuries/illnesses that excluded them from the study. During the study there were players that moved to manual version instead of online questionnaire and used a paper version of the training load assessment. This made the analysing part a lot harder as the results needed to be manually filled to the excel sheets. It also gave a possibility to make errors in the data processing.

9.5 Effect of training load on wellness- assessment

This study shows that there is low but significant correlation between the training load and the wellness- assessment. Similar study (Thorpe et al. 2017) show that subjective questionnaires of an athletes perceived fatique, sleep quality and DOMS tracked the changes in training load. Another study (Saw et al. 2015, 281–291) comparing objective and subjective measures of an athlete's wellbeing proves that subjective measures reflected acute and chronic training loads with superior sensitivity and consistency than objective measures.

9.6 Conclusion

Based on this study the morning-measured ratings of fatigue, sleep quality and DOMS are more sensitive to the changes in training load than the Oura ring HR- derived measures. The wellness-assessment of perceived fatique, sleep quality and muscle soreness gave convinging information about the training status of an athlete and this should always keep in mind when planning practices based on monitoring results. There can be accurate scientific tools to provide information about the autonomic regulation and other physical states of an athlete, but it should always be combined with the subjective measures, such as measures of mood disturbance, perceived stress and recovery and symptoms of stress (Saw et al, 2015, 281–291). No single marker or test such as a correlation coefficient can give a complete picture of an athlete's fitness and fatique status, so practitioners must therefore include a range of measures in their athlete monitoring programs (McGuigan 2017, 103-134).

The study was mainly focused on data analysing, but in the end the players were also asked to give their user experiences about the Oura ring. The results were converging, as most of the players felt that they benefit from the data of the ring. The most valuable data was selected to be the sleep tracking, and how the data helped the athletes to find their optimal sleep rhythm and understand the importance of sleep on recovery. Based on these user experiences it can be suggested that Oura ring can be a good tool to support other monitoring methods.

This research was useful for the subject group, as they received valuable information about their fatique and recovery status during the study. The subject group players got an individual analysis of their wellness-assessments and training load, containing the acute and cumulated load, which they can take advantage of their future training programs. The

Oura Health Oy was also providing the rings for the players, so they can keep tracking their sleep in the future.

I would like to thank Oulun Kärpät Naiset players for participating in this study and a huge thanks to Chief Scientist Officer of Oura Health, Hannu Kinnunen and Oura Health Oy for providing the Oura rings for this study. I would also like to express my gratitude to Kimmo Kantosalo and Mika Vähälummukka for all the guidance and support during the research and writing of this thesis.

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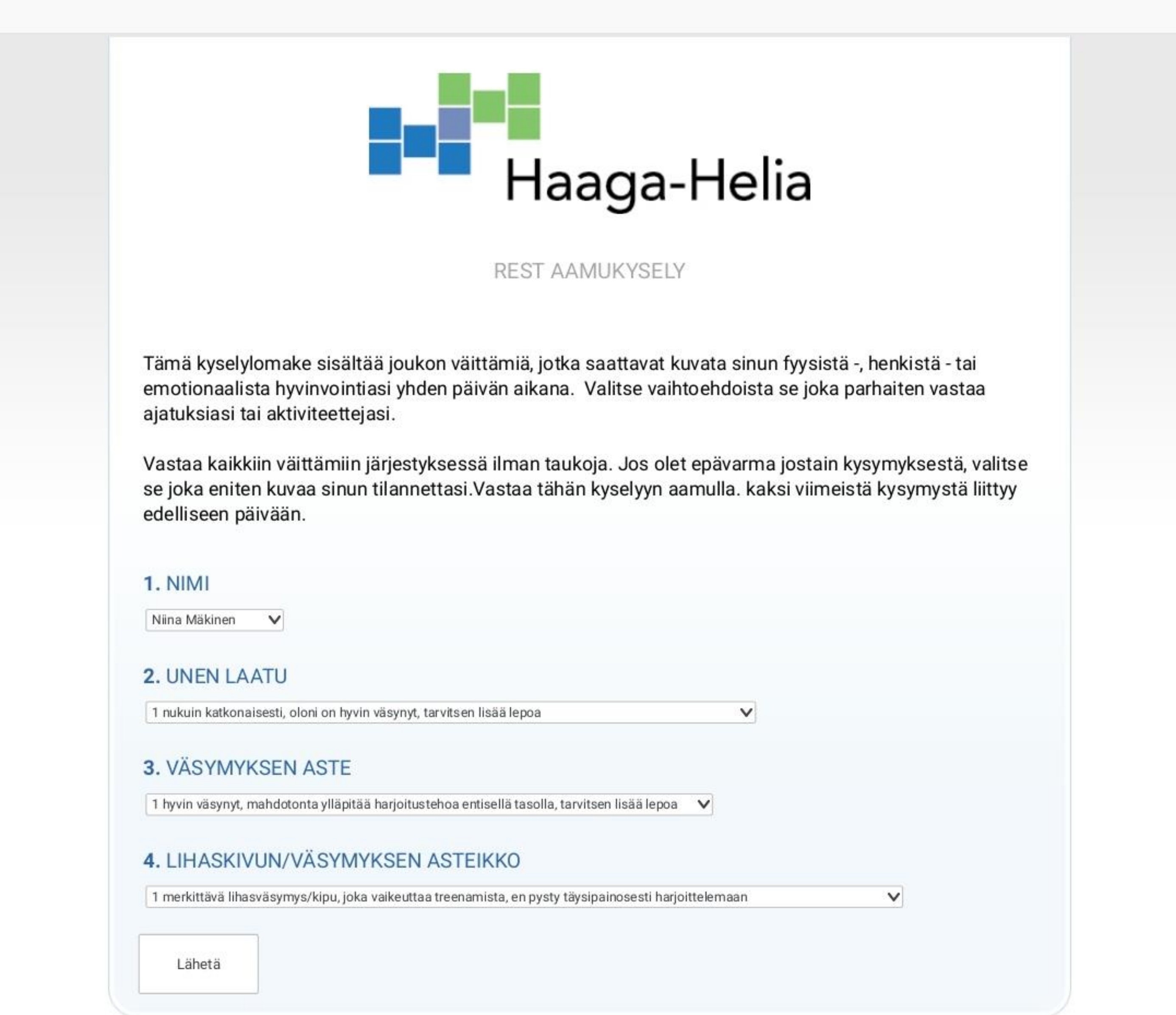
Appendices

Appendix 1. Wellness questionnaire



Haaga-Helia

REST AAMUKYSELY

Tämä kyselylomake sisältää joukon väittämiä, jotka saattavat kuvata sinun fyysistä -, henkistä - tai emotionaalista hyvinvointiasi yhden päivän aikana. Valitse vaihtoehdoista se joka parhaiten vastaa ajatuksiasi tai aktiviteettejasi.

Vastaa kaikkiin väittämiin järjestyksessä ilman taukoja. Jos olet epävarma jostain kysymyksestä, valitse se joka eniten kuvaa sinun tilannettasi.Vastaa tähän kyselyyn aamulla. kaksi viimeistä kysymystä liittyy edelliseen päivään.

1. NIMI

Niina Mäkinen

2. UNEN LAATU

1 nukuin katkonaisesti, oloni on hyvin väsynyt, tarvitsen lisää lepoa

3. VÄSYMYKSEN ASTE

1 hyvin väsynyt, mahdotonta ylläpitää harjoitustehoa entisellä tasolla, tarvitsen lisää lepoa

4. LIHASKIVUN/VÄSYMYKSEN ASTEIKKO

1 merkittävä lihasväsymys/kipu, joka vaikeuttaa treenamista, en pysty täysipainosesti harjoittelemaan

Lähetä

Appendix 2. Questionnaire: Training diary + ratings of perceived exertion

Haaga-Helia

REST ILTAKYSELY

Tämä kyselylomake sisältää joukon väittämiä, jotka saattavat kuvata sinun fyysistä -, henkistä - tai emotionaalista hyvinvointiasi yhden päivän aikana. Valitse vaihtoehdoista se joka parhaiten vastaa ajatuksiasi tai aktiviteettejasi.

Vastaa kaikkiin väittämiin järjestyksessä ilman taukoja. Jos olet epävarma jostain kysymyksestä, valitse se joka eniten kuvaa sinun tilannettasi.Vastaa tähän kyselyyn aamulla. kaksi viimeistä kysymystä liittyy edelliseen päivään.

1. NIMI

Niina Mäkinen

Arvioi tämän harjoituspäivän osalta seuraavia seikkoja:

2. HARJOITUKSEN 1 ALKAMISAIKA

8

3. HARJOITUKSEN 1 KESTO MINUUTEISSA

0 min

4. HARJOITUKSEN 1. RASITTAVUUS

Ei treeniä

5. HARJOITTELUMUOTO TREENI 1

EI TREENIÄ

6. HARJOITUKSEN 2 ALKAMISAIKA

8

7. HARJOITUKSEN 2 KESTO MINUUTEISSA

0 min

8. HARJOITUKSEN 2 . RASITTAVUUS

Ei treeniä

9. HARJOITTELUMUOTO TREENI 2

Ei Treeniä

10. HARJOITUKSEN 3 ALKAMISAIKA

8

11. HARJOITUKSEN 3 KESTO MINUUTEISSA

0min

12. HARJOITUKSEN 3 . RASITTAVUUS

Ei Treeniä

13. HARJOITTELUMUOTO TREENI 3

EI TREENIÄ

Lähetä