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RASMUS PIND

Quantification of internal training load and its use in different practical training applications

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Institute of Sport Sciences and Physiotherapy, Faculty of Medicine, University of Tartu, Tartu, Estonia

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II. **Pind R**., Purge P., Mäestu E., Vahtra E., Hofmann P., Mäestu J. Session Rating of Perceived Exertion Is Different for Similar Intensity and Duration Prescribed Low-Intensity Sessions and Has a Different Effect on Performance in Young Cross-Country Skiers. The Journal of Strength and Conditioning Research, Published Ahead of Print, 1–7. DOI: 10.1519/JSC.0000000000004180.

III. **Pind R**., Hofmann P., Mäestu E., Vahtra E., Purge P., Mäestu J. Increases in RPE Rating Predict Fatigue Accumulation Without Changes in Heart Rate Zone Distribution After 4-Week Low- Intensity High-Volume Training Period in High-Level Rowers. Frontiers in Physiology, 2021; 12, 1−10. DOI: 10.3389/fphys.2021.735565.

In Papers I, II and III Rasmus Pind had primary responsibility for study protocol development, enrolment of the participants, performing measurements, data analysis, and writing the manuscripts.

LIST OF ABBREVIATIONS

AU	arbitrary unit
BF_{10}	Bayesian factor in favour H_1 over H_0
BMI	body mass index
CI	confidence interval
ES	effect size
G_{high}	high training load group, based on the median rating of RPE during low-intensity sessions
G_{low}	low training load group, based on the median rating of RPE during low-intensity sessions
HR_{max}	heart rate maximum achieved during the incremental test
Mod	moderate
RPE	rating of perceived exertion
sRPE	session rating of perceived exertion
sRPE.I	individual VT1 and VT2 effort-based training load distribution method
sRPE.S	training load distribution based on specific RPE values
sRPE.W	training load distribution based on Wallace et al. (2009)
$sRPE_{Easy}$	internal load of training sessions rated as 4 or less on a 10-pt RPE scale
$sRPE_{Hard}$	internal load of training sessions rated as 7 or higher on a 10-pt RPE scale
$sRPE_{Mod}$	internal load of training sessions rated as 5 or 6 on a 10-pt RPE scale
TRIMP	training impulse
V_E	minute ventilation
$\dot{V}O_{2max}$	maximal oxygen consumption
VT1	first ventilatory threshold
VT2	second ventilatory threshold
$W_{max/kg}$	maximal power output relative to bodyweight
XC	cross-country

1. INTRODUCTION

Every four years, in recent decades, 10,000 athletes from 200 countries, and hundreds of thousands of spectators gather to participate in and watch a sporting event followed by billions of people around the world. The Olympics attract people from all over the world. It is a sporting event, where athletes prepare themselves for their best possible performance and the best result. To reach this level, the process of training has become more and more complex, where every detail that is possible to control, will be paid attention to. However, it is not only Olympics or Championships that the athletes aim for. Different types of competitions have widened; thus, athletes need to perform at their top potential for much longer periods than a couple of decades ago. This makes training planning and adaptation a much more complicated process, as not only training but also recovery play a significant role, forcing coaches and athletes to search for new methods, markers of athletic status, performance tests, recovery strategies etc. Therefore, monitoring methods and systems for athletic training and performance are becoming commonplace, particularly in high-performance sports programs (McGuigan, 2017).

The training stimulus in competitive sports is usually described as a combination of training intensity, duration, and frequency. It is generally believed that these three factors combined with adequate recovery produce an adaptive response that should lead to improvements in performance. A 6th century BC farm boy Milon of Croton was said to have achieved the feat of lifting the bullock by starting in childhood, lifting, and carrying a growing bullock daily as it grew to maturity (Foster et al., 2021). Nowadays this is, however, a tricky part in the training and monitoring process to determine the exact timepoint where adaptive training might turn maladaptive. Therefore, one very important component in the training process is to measure and monitor training load, which could provide individuals with an additional marker, that could be used in the preparation for the competitions in athletic training.

Contemporary training load monitoring began in Germany in the late 1930s (Foster et al., 2017), where interval training was developed to quantitate the training load. This type of training was based on several repetitive runs (100–400 m repetitions) up to the heart rate of 180 beats per min and allowing the recovery between intervals with the decrease of the heart rate below 120 beats (Foster et al., 2017). The training load in the context of athletic training has been described as the input variable that is manipulated to elicit the desired training response (Coutts et al., 2017). Training load can be described by two different concepts – external or internal load. Most of the training programs have been described by the external load – training time, covered distance, lifted weight, etc. However, it is the relative physiological stress imposed (internal training load) and not the external load completed by the athlete, that determines the stimulus for the training adaptation (Halson, 2014). Internal load refers to the physiological stress during training, that determines the adaptation to the training program. Although, due to time-consuming feedback and high cost, most internal load measuring tools are not suitable for use in practical sports settings on daily basis. To measure internal training load, the following measurements are being considered – blood lactate concentration, oxygen consumption, biochemical/hematological assessments (Bourdon et al., 2017). Those options, however, require specific apparatus and therefore, are not always feasible in practical settings (Barroso et al., 2014; Impellizzeri et al., 2004). Currently, in practice, the most widely used method for internal load measuring is heart rate. However, it can be a poor method for evaluating intensity during interval, intermittent, resistance training, and plyometric training (Barroso et al., 2014). Similarly, heart rate does not always accurately reflect the metabolic demands of the exercise (Gilman, 1996). Heart rate may excessively change for a given exercise intensity if the duration of physical activity is long (Gilman, 1996; Lucia et al., 1999; Maunder et al., 2021) or if the athlete is fatigued as the result of heavy training load periods.

One practical method in addition to the objective measurements, to measure internal load is the widely used psycho-physiological tool called the rating of perceived exertion (RPE) (Borg, 1970), which can be further used for training load calculation. Training session based rating of perceived exertion (sRPE) reflects an individual's subjective response to the training load (Foster et al., 2001). The method is 27 years old, as of 2022, and has become a popular alternative to represent exercise intensity versus objective methods such as heart rate and blood lactate (Foster et al., 2021). The sRPE method is a simple method (Foster, 1998; Foster et al., 2001), and has already been used in different endurance sports (Foster et al., 2001; Roos et al., 2018; Sanders et al., 2018; Seiler and Kjerland, 2006; Tran et al., 2015; Wallace et al., 2009, 2014).

Internal training load, quantified by the sRPE method, can be modified during the training cycle to increase or decrease fatigue depending on the phase of training, for physical performance purposes (Meeusen et al., 2013). In endurance sports, it is common to organize the intensity continuum into specific zones. Similarly, it has been shown that these heart rate-based zones could be matched to subjective, RPE values that correspond to aerobic and anaerobic threshold (Seiler and Kjerland, 2006). This further means that training load could be quantified by *Easy, Moderate* or *Hard* and be studied for practical use to monitor the training process and to improve performance. The current dissertation aims to provide useful information to athletes, coaches, and practitioners with a practical tool to help them capture their desired dreams in the sports performance context.

2. REVIEW OF THE LITERATURE

2.1. External and internal training load

Athletes frequently use manipulations in training load (intensity, duration, and frequency) to stimulate training adaptation. Furthermore, different types of training methods (low- and high-intensity training, interval training, maximal speed training etc.) are used in different sports disciplines, including competitive swimming, cross-country skiing (XC skiing) and rowing to improve performance. It is however suggested that training intensity itself, rather than training volume or frequency, is the key factor in producing a training effect (Mujika et al., 1995). Recent papers (Hofmann and Tschakert, 2017; Maunder et al., 2021) indicate the importance of the proper intensity–duration relationship not only in the high-intensity domain but also in the low-intensity domain.

Training load in the context of athletic training has been described as the input variable that is manipulated to elicit the desired training response (Coutts et al., 2017) and can further be described by two different concepts – external load (i.e., training time, covered distance, lifted weight, generated power etc.) or internal load (heart rate, oxygen consumption, blood lactate etc.) (Bourdon et al., 2017). In practical settings, most of the training tasks are based on the external load, however, components of internal load can also be used. For example, running 10 km (external load) at the heart rate of 145 beats per min (internal load). However, changes in performance depend on the individual adaptation of the athlete to the described external load and therefore, it is important to monitor the athletes' physiological responses (i.e., internal training load) from the external stressors.

Monitoring internal training load usually requires specific equipment, which can be sometimes inconvenient for application in a practical setting, especially in younger athletes if the specific equipment might be unavailable for them. Heart rate is valid and currently, the most common measure for measuring internal load, especially for endurance disciplines (Halson, 2014; Impellizzeri et al., 2019) and has been considered as a good exercise intensity marker during the training session (Lambert et al., 1998). Heart rate can also be used for calculating internal training load using different methodologies (Halson, 2014). For example, Banister (1991) developed the training impulse (TRIMP) as a method to quantify training load. The method is based on the exercise intensity calculated by the heart rate reserve method and the duration of exercise. For different activities where heart rate is the dominant physiological signal representing the intensity of the exercise, the TRIMP method is valid and works well. Although, it is mathematically complex and different activities (disciplines) with different values for maximal heart rate need to have individual anchors by measured values for resting and maximal heart rate, making this parameter harder to use in the practice (Foster et al., 2021). However, this method has been helpful to understand the training response using heart rate measurement and the method has later been modified by Edwards (1994) and Lucia et al. (2003). In addition, Lucia's TRIMP is calculated by multiplying the time spent in three different heart rate zones (first ventilatory threshold (VT1) and second ventilatory threshold (VT2) as anchor points) by a coefficient (1 for a zone below VT1, 2 for the zone between VT1 and VT2, and 3 for zone higher than VT2) relative to each intensity zone and then summating the results (Lucia et al., 2003). This method is similar to that of Edwards (1994). The main difference between Edward's and Lucia's methods is that the heart rate zones defined by Lucia et al. (2003) are based on individual physiological parameters obtained in the laboratory, whereas Edward's (1994) method uses standardized predefined zones as percentages of heart rate maximum. However, it should also be considered that heart rate is not very well suitable for evaluating training intensity and internal load in interval, intermittent, weight or plyometric training (Foster et al., 2001), or even for specific disciplines like the swimming (Wallace et al., 2009).

2.2. The sRPE method for calculating training load

The sRPE method of monitoring training load was developed in 1995 (Foster et al., 1995) while trying to simplify the TRIMP method. The method is a simple, low-technology and practical to measure or quantify internal load, which reflects an individual's subjective response to external training load (Foster et al., 2001) taking into account both, the duration and intensity components. The method originates from the RPE method, developed by Borg (1970). In addition to the objective prescription of exercise intensity using heart rate measures, the perception of effort, which may vary individually, can be obtained by subjective ratings such as the commonly used RPE scale (Foster et al., 2001). The perception of effort can be defined as the subjective effort, strain or fatigue perceived during the training session (Robertson and Noble, 1997). The RPE scale with the values from 0 to 10 (Table 1), is being used by the athletes, by answering the question: "How hard was your workout?" usually within 30 min after the end of each training session. With the sRPE method, internal training load is calculated by multiplying the athlete's RPE obtained 30 min after the session completion (RPE, 0–10pt scale; Table 1) by the duration of the session (min).

$$sRPE\ (internal\ training\ load) =$$
$$RPE\ (0 - 10pt\ scale)\ \times\ duration\ of\ the\ session\ (min)$$

Table 1. Foster's 10-pt RPE scale. Subjects rate the effort 30 minutes after each training session by answering, "How hard was your workout?" (Foster et al., 2001).

Rating	Descriptor
0	Rest
1	Very, Very Easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	-
7	Very hard
8	-
9	-
10	Maximal

The purpose of the time lag to obtain RPE was aimed to prevent particularly hard or easy segments, especially when these parts occur at the end of the session and therefore, have an influence on the sRPE which was intended to be the overall rating of the session (Foster et al., 2001). However, in later studies it has been confirmed that sRPE even if obtained several days after the particular training session, was not significantly different from the value reported 30 min after the session (Christen et al., 2016), indicating the robustness of the instrument.

As being a simple and valid method (Foster, 1998; Foster et al., 2001), sRPE has already been applied and used in different endurance sports (Foster et al., 2001; Roos et al., 2018; Sanders et al., 2018; Wallace et al., 2014) including swimming (Wallace et al., 2009), XC skiing (Seiler and Kjerland, 2006) and rowing (Tran et al., 2015). sRPE has shown high reliability with different objective heart rate-based methods (García-Ramos et al., 2015; Lupo et al., 2014; Rodríguez-Marroyo et al., 2012; Seiler and Kjerland, 2006). The correlations between sRPE and heart rate are valid by up to $r=0.90$ (Foster et al., 2001). As well, a recent study (Falk Neto et al., 2020) showed a high correlation between sRPE and blood lactate concentration measured 30 min after the session ($P=0.015$). It has also been indicated that the 0 to 10 category ratio (CR-10) scale and the classical 6–20-point scale, which is commonly used for subjective evaluation of exercise intensity, fit both well in relation to the %heart rate reserve and blood lactate concentration and relate with each other during the incremental exercise test (Arney et al., 2019a). This suggests that a 20-point scale can similarly be used for training load quantification. However, it should be noted that in this case, the calculated training load values are not comparable due to the use of different numerical values of the scales, but the overall relationship between training load values is internally coherent (Arney et al., 2019b). It should also be taken into account that there are several factors that can affect RPE response, like athlete's training experience, cognition, and memory (Eston, 2012). However, whatever the age range, the use of the RPE in sport, exercise, and rehabilitation is founded on its strong relationships with exercise intensity and physiological factors (Eston, 2012). This concept has been researched mainly in terms of describing relationships between exercise intensity and sRPE (Impellizzeri et al., 2004; Wallace et al., 2009) and in recent years also to prescription on the effort of the entire workout as well as for accumulation of internal training load after multiple workouts (Brink et al., 2014).

2.3. Relationships with sRPE based training load and performance (Paper I)

The organisation of the training intensity continuum into specific zones is common practice in endurance sports. Most national sport governing bodies and different endurance disciplines use an intensity scale based on the ranges of heart rate relative to heart rate maximum and associated typical blood lactate concentration range (Seiler and Tønnessen, 2009). Several studies examining the training intensity distribution (Esteve-Lanao et al., 2005; Seiler and Kjerland, 2006; Zapico et al., 2007) have employed the aerobic and anaerobic thresholds or VT1 and VT2 to divide the heart rate continuum into three different intensity zones, which is probably one of the most robust method and very widely used. Furthermore, the heart rate-based intensity categorization methods which use more than 3 zones, usually have the same (aerobic and anaerobic threshold) anchor points to build the logic of the zones (Seiler and Tønnessen, 2009).

The three intensity zone model is most frequently defined by heart rate (Seiler and Kjerland, 2006), which can further be applied for calculating training load by using the TRIMP method. For example. Lucia et al. (2003) developed a method with the use of the VT1 and VT2 as physiological landmarks to define three heart rate zones and a subsequent weighing factor to calculate training load. However, such a heart rate-based time-in-zone approach might underestimate the time spent working at high-intensity (due to heart rate lag time during intervals) or the heart rate drift over the course of a longer workout (Seiler and Kjerland, 2006; Maunder et al., 2021). In addition to the general "overall internal load" parameter of the training session, previous studies (Esteve-Lanao et al., 2005; Muñoz et al., 2014; Seiler and Kjerland, 2006; Seiler, 2010; Zapico et al., 2007) have also used RPE as effort-based quantification to distinguish between *Easy, Moderate* or *Hard* training sessions using the same VT1/VT2 anchor points as for Lucia TRIMP method (Seiler and Kjerland, 2006; Wallace et al., 2009). Accordingly, Seiler & Kjerland (2006) indicated that sRPE and session-goal heart rate method were in agreement of 92% in the training sessions of elite-level XC skiers if the RPE scale was categorized into three zones, with the ratings of 0–4 indicating training at intensities below aerobic threshold, 5–6 intensities between aerobic and anaerobic threshold and 7–10 indicating training above the intensities of anaerobic threshold. In adolescent swimmers, a similar concept has been used to investigate the correspondence of the internal load between the swimmer and the coach during a training session (Barroso et al., 2014; Wallace et al., 2009). However, the cut-off points between the zones were at lower effort rates (0–2, 3–5, 6–10, respectively) compared to those used by Seiler and Kjerland (2006). Wallace and colleagues (2009) further argued that if a higher number of swimming intervals was used, the strength of the correlation between sRPE and heart rate-based internal training load could be lower, therefore proper internal load categorization is important for performance analysis. Based on these results we can further calculate or quantify training load as *Easy*, *Moderate*, or *Hard* session.

For practical application, different measures of internal training load should be investigated in interaction with changes in performance and the chosen training load measure should be selected based on the relationship of the load and the outcome interest (Manzi et al., 2009; Sanders et al., 2017). A recent study in highly trained cyclists (Sanders et al., 2017) indicated that the strongest relationships with fitness and performance were found if quantification methods that integrate individual physiological characteristics were used. Furthermore, Munoz et al. (2014) found that training load (TRIMP) accumulated below aerobic threshold during the 18-week training cycle was significantly related to Ironman performance. However, to the best of our knowledge, there is no study in the literature that has investigated the categorization of sRPE based internal load with changes in performance.

It has been shown that the training experience of the athlete can possibly influence the sRPE response after the session (Barroso et al., 2014; Wallace et al., 2009). The nature of the relationship between the prescribed exercise load and the expected training outcome or response must be known in order to have a positive impact on the performance (Sanders et al., 2017). Therefore, the subjective RPE ratings that correspond to aerobic and anaerobic thresholds during laboratory testing, could further validate the subjective internal training load scale according to individual perception.

2.4. Different RPE during similarly prescribed sessions (Paper II)

Planning the total duration of a single training session is probably easier at higher intensities, as exercising above anaerobic threshold (VT2) leads to a sustained increase in blood lactate concentration and early fatigue (Tremblay et al., 2005; Tschakert and Hofmann, 2013) and even small increases in intensity result in faster time to exhaustion. Furthermore, the aim of high-intensity training is also rather straightforward – to induce a distinct functional and/or structural load by the end of the training session in order to stimulate the adaptation (Egan and Zierath, 2013). On the other hand, accumulated duration below the aerobic threshold (first lactate threshold or turn point) can be 6 hrs or even more during a single session (Seiler, 2010) and within this low-intensity domain, a small change in intensity usually does not affect significantly the occurrence of acute fatigue. As applied in practice, short low-intensity sessions are known to stimulate recovery, whereas moderate duration sessions may stabilize performance or even improve if longer distance or longer duration is used (Hofmann and Tschakert, 2017).

Different training intensities target different functional or structural adaptations; however, the session duration usually is not individually prescribed, although the length of each training session seems to be crucial for any specific intensity level to induce training effects (Hofmann and Tschakert, 2017; Viru, 1992). For example, during low-intensity exercises, longer durations are needed to stimulate hormonal changes and therefore, different adaptation effects may occur using the same intensity with different duration (Tremblay et al., 2005). However, numerous recently published articles on the endurance training (Bourgois et al., 2019; Solli et al., 2020; Tønnessen et al., 2014; Undebakke et al., 2019) provide very limited information on how low-intensity high-volume endurance training and the interaction between changes in training intensity and/or duration in the low-intensity domain (around first lactate threshold or turn point) might influence endurance performance (Hofmann and Tschakert, 2017) or acute effects of a training session. While this is true, potential methods of an optimal duration for each individual intensity domain are still missing (Hofmann and Tschakert, 2017; Pettitt, 2016).

One potential method for measuring the intensity-duration relationship was presented by Pettitt (2016). This power-duration relationship allows defining specific duration domains for endurance-type exercise such as recovery, stabilization or development effects which are dependent on the degree of fatigue-induced (Hofmann and Tschakert, 2017). Therefore, for each defined intensity, a different response to acute training occurs when manipulating the duration of the session. For example, a 30 min session at aerobic threshold could be a recovery session for a young athlete, but when performed for 90 min for the same athlete, it might already enhance endurance ability. Additionally, the sustainable duration performing the same relative intensity (e.g. same percentage of thresholds) may be different between subjects, dependent on the degree of training state as shown for subjects and patients with different training status (Mezzani et al., 2010). As the determination of the power-duration relationship needs several all-out tasks varying in distance and speed, this method is rather difficult to use in the routine practical training situation.

To overcome this problem, the RPE scale was proposed as one potential solution (Seiler and Sjursen, 2004) to identify reference markers for different duration effects. As athletes perceive their training differently, working 60 min at the same submaximal intensity can be rated differently with respect to effort depending on the athletes training status. In contrast, applying similar intensities and duration might therefore result in differences in the session effort between the athletes. Endurance athletes, including XC skiers, frequently perform low-intensity high-volume training sessions to improve their endurance capacity or to recover from *Hard* sessions (Laursen, 2010; Solli et al., 2017; Tønnessen et al., 2014), which is typical for the so-called polarized training model (Seiler and Kjerland, 2006; Stöggl and Sperlich, 2014). In such cases, differences appear in cumulative training load, which could induce different adaptations. To the best of our knowledge, such information is lacking for young endurance athletes. During exercise below first turn point intensities, differences in acute responses are only detected or recognized by an athlete after a long duration of exercise. Therefore, reference markers, especially for low-intensity training (objective or subjective) (Halson, 2014) could help to improve exercise training prescription for acute training effects in terms of intensity-volume interaction and secondly, it is unknown whether those acute effects lead to different performance adaptations.

Therefore, the integration of RPE and heart rate data could provide additional information about the fatigue status or overtraining risk of athletes. However, there is limited information on the use of RPE and heart rate integration during a high-volume, low-intensity training cycle that is commonly used in rowing, XC skiing and swimming during the preparatory period to obtain subjective fatigue development.

2.5. Associations between fatigue and internal training load (Paper III)

To achieve high performance, athletes need to train a lot and tolerate high training loads (Seiler and Tønnessen, 2009). Accordingly, it has been demonstrated with rowers that low-intensity training kilometres are positively related to success in the Championships (Hagerman and Staron, 1982; Mäestu et al., 2005; Steinacker, 1993) and therefore, periods of low-intensity and high-volume training are frequently used during preparation to optimise performance. Such increases in low-intensity training may reach up to 50% of the regular training volume (Buchheit et al., 2013; Comotto et al., 2015; Rämson et al., 2008; Thornton et al., 2017). However, the risk of overreaching/overtraining increases with increased training volume and particularly with monotonous training (Fry et al., 1992; Lehmann et al., 1992, 1993; Meeusen et al., 2013). The continuum from rested state to overtraining syndrome is complex and its progression can be described as an increase in time that is needed for recovery to eliminate fatigue (Meeusen et al., 2013). However, to further stimulate performance improvement high training loads are used but altered with recovery periods for proper adaptation, i.e., non-functional overreaching (Meeusen et al., 2013). The scientific literature is still in search of different markers that can be used to monitor the training process to avoid periods where athletic performance and trainings are compromised for longer periods and when recovery is needed (Jones et al., 2017). Additionally, by the time an underlying problem has been confirmed in the laboratory, the athlete’s competitive results may already be compromised (Meeusen et al., 2013). Therefore, the biggest challenge in the training and training monitoring process is to determine the timepoint where adaptive training might turn maladaptive. However, due to delayed effects and several interdependencies, it is a complex and complicated process and difficult to measure.

As indicated in previous studies (Halson, 2014; Meeusen et al., 2013), the subjective or psychometric instruments are sensitive in terms of changes either in training load, performance, or excessive fatigue. The advantage of psychometric instruments is that they are relatively simple and inexpensive to determine the status of an athlete and his/her response to the training session or training cycles (Steinacker et al., 2000). The Recovery-Stress Questionnaire for Athletes (RESTQ-Sport) was developed to measure the frequency of current stress along with the frequency of recovery-associated activities (Kellmann and Kallus, 2001) and has been shown effective to monitor the training status of rowers (Kellmann and Günther, 2000; Kellmann et al., 2001; Mäestu et al., 2006). Previous studies relating changes in training load and psychometric instruments exclusively studied manipulation of external load during high-load training periods (González-Boto et al., 2008; Jürimäe et al., 2004; Scott and Lovell, 2018; Steinacker et al., 2000), and suggested that changes in the external training load are reflected by changes in the RESTQ-Sport scales (González-Boto et al., 2008; Mäestu et al., 2006). However, less focus has been committed to the interaction between subjective instruments and changes in the internal training load (Buchheit et al., 2013; Collette et al., 2018; Comotto et al., 2015). A previous study with junior-elite triathletes (Comotto et al., 2015) evaluated the individual responses to training by monitoring sRPE and Profile of Mood States. These authors further suggested that monitoring of mood and perceived exertion during periods of heavy training may help individualize training to prevent overtraining during training camps.

Although RPE or sRPE have been mostly considered measures of exercise intensity (Foster et al., 2001), recent evidence from the literature also suggests that sRPE could be affected by external factors related to training, i.e. the duration of the session or fatigue. For example, the recent experimental study indicated that during 30 min constant running exercise, RPE values were higher compared to similar intensities during a 15 min run (Jesus et al., 2021). However, the effect was seen for intensities described as moderate or hard and not for low-intensity exercise. Furthermore, an increase in training duration, despite being performed at the same intensity, and with evidence of a consistent internal and external training load, had an influence on the post-exercise RPE (Fusco et al., 2020a). It was indicated that during an extensive swimming interval session (blood lactate concentration around 6 mmol/l), RPE increased constantly throughout the session if additional interval blocks were added to the session. Despite working at the same external and internal intensity, RPE increased with the training duration (Fusco et al., 2020a).

Additionally, a recent study (Fusco et al., 2020b) also supports the concept that sRPE could be a potential tool that may detect accumulated fatigue across multiple training days. The use of constant high-intensity sessions, heart rate and RPE values indicated a relatively constant pattern over the 2-week training period (Fusco et al., 2020b). However, there were significant differences between RPE values at the end of the training period compared to the reference training at the beginning of the study. Thus, those results support the concept that RPE or the resulting internal load as sRPE, provides further information on accumulated fatigue during prolonged exercise (Fusco et al., 2020a) or across multiple training days (Fusco et al., 2020b).

Using the data from the cycling Grand Tours, Sanders et al. (2017) proposed that changes in the ratios of intensity and load measures (including measures of heart rate and RPE) could reflect increases in fatigue that might not be well detected by analysing solitary intensity/load measures. Despite being stated almost three decades ago, there is a need for training related markers that optimally combine aerobic and anaerobic training and manipulate the training load to correspond to the respective race distance and time (Wakayoshi et al., 1992). Furthermore, with the aim to optimise performance during the training cycles, training sessions need careful planning and monitoring, to prevent both undertraining and overtraining (Meeusen et al., 2013) and an optimal balance between training and recovery has to be maintained to maximize physical performance (Mujika et al., 2018). Because of the simplicity of sRPE, it has been possible to use it to analyse the data derived to examine the relationship between training load and performance (Foster et al., 2012). Training load, quantified by the sRPE method, can be modified during the training cycle to increase or decrease fatigue depending on the phase of training and to minimize training side effects, such as inadequate recovery that could lead to overreaching or overtraining syndrome (Meeusen et al., 2013).

3. RESEARCH AIM AND PURPOSES

The main aim of the current dissertation was to investigate different measures of internal and external training load during different duration training cycles and their relationships with performance and fatigue.

According to the main aim the specific purposes were to:

1. Investigate the association between sRPE and its categorization with the changes in swimming performance in adolescent swimmers (Paper I).
2. Analyse whether post-session RPE and the resulting internal load (sRPE) could differ among subjects when volume and intensity are matched during a training period in young XC skiers (Paper II).
3. Analyse whether XC skiers with high or low post-session RPE response, and the resulting internal load have different adaptations after 1-week low-intensity high-volume training period (Paper II).
4. Investigate the interaction of training load quantification using heart rate and RPE-based methodology, and the relationship between internal training load parameters and subject's *Fatigue* status in high-level rowers during volume increased low-intensity training period (Paper III).

4. METHODS

4.1. Subjects

The current dissertation is combined of three different studies and the description of the subjects in all studies is presented in Table 2.

Twelve (4 girls and 8 boys) national level swimmers initially participated in Study I. All the subjects had passed peak height velocity, based on the annual growth parameters obtained during the regular medical checks. However, 4 of the swimmers were later excluded from the data analysis for higher validity because of the exclusion criteria (criteria indicated later in the paragraph). The number of subjects included in the final analysis of Study I was 8 (2 girls and 6 boys).

Thirteen (4 girls and 9 boys) national level young XC skiers participated in Study II. All subjects completed the whole study and none of them was excluded from the final analysis.

Participants in Study III were 27 high-level rowers (4 women and 23 men) of the Estonian National Rowing Team. Depending on the age group, they were the members of the National U-19, U-23, or Senior A-Team. During the study period, eight rowers were excluded from the analyses, due to the exclusion criteria. Therefore, the number of participants included in the final analyses was 19 (2 women and 17 men).

Table 2. Final sample size and main characteristics (mean ± SD) of the participants from Paper I, II and III that were included in the present dissertation.

	Paper I National level swimmers	**Paper II National level XC skiers**	**Paper III High-level rowers**
Sample size (n)	8	13	19
Age (y)	16.4 ± 2.1	13.4 ± 1.9	23.5 ± 5.9
Body mass (kg)	67.7 ± 4.0	48.8 ± 9.4	87.0 ± 11.0
Body height (m)	1.81 ± 0.10	1.58 ± 0.12	1.87 ± 0.07
BMI ($kg\cdot m^{-2}$)	20.6 ± 3.0	19.4 ± 2.1	24.7 ± 1.9
$\dot{V}O_{2max}$ ($ml\cdot min^{-1}\cdot kg^{-1}$)	50.0 ± 4.0	51.2 ± 8.0	58.9 ± 5.8

BMI – body mass index; $\dot{V}O_{2max}$ – maximal oxygen consumption; XC skiers – cross-country skiers

All participants in Paper I and II competed regularly on the local and national levels. The participants in Paper III further competed at the international level and included medal winners from different European or World Championships. The exclusion criteria for all the studies were the following: (i) having provided less than 95% of training data or (ii) having missed more than 5% of the training sessions due to sickness or other reasons.

In all three studies, testing procedures and related risks were described to all the subjects and their parents or legal guardians (where applicable) before the written informed consent was signed by participants, or for those under 18 years of age, by both the participant and their legal guardian to participate in the study. In all three studies, study procedures and protocols were in accordance with the Declaration of Helsinki and were approved by the research and ethics committee of the University of Tartu, as indicated by the following approvals of 272T-11, 291T-16, and 273T-9.

4.2. Study design

4.2.1. Experimental protocol

During the first visit to the laboratory, all procedures were again explained to the participants. After providing informed consent, the height (Seca Height Rod Model 225, Seca GmbH & Co, Hamburg, Germany) and body mass (A&D Instruments Ltd, Abington, UK) of the participants were measured to the nearest 0.1 cm and 0.1 kg, respectively. During the same visit, all the participants underwent an incremental exercise test. For Studies I and II the same incremental test was conducted at the beginning and at the end of the training period.

Paper I, with national-level swimmers, was conducted as a 10-week period preceding the National Winter Swimming Championships. The training period was completed between October and January. During the training period, daily training data was collected. Additionally, a 100-m swimming performance was performed during the first training session. The same swimming performance tests were conducted after the 10-week study period.

Well-trained national level XC skiers, in Paper II, took part in a 1-week training period, which was conducted at the end of the preparatory period (October) as the first snow training camp. The overall training volume during the training camp was planned about 20% higher compared to their previous training volume. During the training camp, daily training data were collected. Double poling performance and subjective ratings of *fatigue* and *will to train* were collected during the first two days, then in the middle and during the last two days of the training camp. The ratings were asked in the morning before the first training session

High-level rowers in Paper III participated in a 4-week training camp at the end of the winter preparatory period from March to April. During the training camp, the 1st week of the study was characterized as the baseline week, without an increase in training load compared to previous weeks. During the next 2 weeks, the training load was doubled, and the fourth week was designed as a recovery week. Daily training data of each training was collected. Additionally, RESTQ-Sport questionnaire (Kellmann and Günther, 2000) was filled at the beginning of each week.

4.2.2. Incremental testing protocol

In all studies, the first visit included an incremental exercise test until volitional exhaustion. The test was performed on a cycle ergometer (Lode Corival, Groningen, The Netherlands), on a ski ergometer (Skierg, Concept Inc., Morrisville, VT, USA), or on a rowing ergometer (Concept II, Model B, Morrisville, VT, USA), in Paper I, II and III, respectively.

National level swimmers in Paper I performed the test on a cycle ergometer with the initial workload of 50 Watts (W) and the load was increased every two min by 25 W. The incremental test was conducted twice, at the beginning and at the end of the 10-week training period (after the Winter National Championships). In Paper II, a double poling ski ergometer test was conducted at the beginning and at the end of the 1-week training camp. The second test was conducted 2 to 3 days after the last training session. The initial workload during the test was 30 or 40 W and the workload was increased every min by 5 to 20 W, depending on the performance level of the XC skier to obtain comparable test duration within the subjects. The second incremental test in Paper II was performed similarly to the first test but without gas exchange measures. In Paper III, the incremental test was performed on a rowing ergometer, with an initial workload of 40 W and the increments were 20 W after every min until volitional exhaustion (Hofmann et al., 2007).

During the incremental exercise tests, expired gases and heart rate were continuously measured using a portable metabolic device (Metamax 3B, Cortex Biophysic GmbH, Leipzig, Germany) to determine performance parameters. $\dot{V}O_{2max}$ was defined as the highest average $\dot{V}O_2$ during a 30 s period. We refer to $\dot{V}O_{2max}$ also for our young and adolescent subjects as they were experienced to produce maximal effort and have been tested for incremental tests before during their career (Poole and Jones, 2017). To ensure reaching the maximal effort the following criteria were used: failure to increase $\dot{V}O_2$ despite an increase in work rate or respiratory exchange ratio exceeding 1.1. The VT1 and the VT2 were determined as shown previously (Hofmann et al., 2007). In brief, VT1 was determined as the first increase in ventilation (V_E) accompanied by an increase in the equivalent for oxygen consumption ($V_E/\dot{V}O_2$) without an increase in the equivalent for carbon dioxide output (V_E/VCO_2). VT2 was determined as the second distinct increase in V_E accompanied by an increase in both $V_E/\dot{V}O_2$ and V_E/VCO_2. All determinations were performed within defined regions of interest such as between first workload and 65% of maximal performance (P_{max}; W) for VT1 and between VT1 and P_{max} for VT2. Determinations were performed by visual inspection from two independent and experienced researchers. If there was disagreement between the two observers, a third reviewer was used. Heart rate was measured continuously and registered every 5 s via chest strap telemetry (Polar Electro. Kempele, Finland). At the end of each workload, the participants were asked how hard they perceived the current workload on the modified 10-pt scale (Foster et al., 2001).

In Papers II and III, individual VT1 and VT2 related target heart rate zones were used for athletes to quantify their training intensity during the trainings as follows: HR Z1 (the time period with heart rate values lower or equal to VT1), HR Z2 (the time period with heart rate values between VT1 and/or equal to VT2), HR Z3 (the time period with heart rate values above VT2). Individual target heart rate zones were then provided to the athletes for the upcoming training period.

4.2.3. External training load

In all 3 studies, each training session was designed and conducted by the coach with no input of the training process from the researchers.

In Paper I all subjects have trained under the same coach with similarly prescribed training programs before the beginning of the study. The external training load was planned by the coach using swimming distance in meters and three different training intensities characterized by swimming speed. Individual swimming speeds for describing training intensities were determined at the beginning of the preparatory period in September by the coach using the lactate performance curve and matched against aerobic and anaerobic thresholds (Hofmann et al., 1994). The training plan was compiled based on the principles listed next. *Easy* training consisted of low speed, long-distance sessions, with intensities mostly below aerobic threshold. *Moderate* intensity sessions included specific technique or pace training corresponding to higher intensities than aerobic threshold but lower than anaerobic threshold. *Hard* sessions included high-intensity (speeds at 90–100% intensity) interval and repetition trainings. Each session could cover several types of training, e.g., included low-speed swimming and some high-intensity bouts. Based on the categorization scales and athlete's RPE, the training was quantified as *Easy*, *Moderate* or *Hard* after performing the session. Swimming speeds were described individually for each training to match the targeted session goal and were kept within the suggested range during the training session, heart rate monitored by watches or by palpation. The overall 10-week training plan compiled by the coach included 63% *Easy*, 20% *Moderate* and 17% *Hard* sessions based on the subjective rating of the coach on the same 10-pt scale as used by the subjects. Training sessions took place in a 25-m heated pool (27–28 °C) and were performed as the final preparation phase for the National Winter Championships.

In Paper II all subjects have trained under the same coach with similarly prescribed training programs before the study. Skiing sessions were planned and conducted by the coach using the duration, intensity, and technique of XC skiing as external load characteristics. The overall training volume during the training camp was planned about 20% higher compared to the previous training volume. Nine training sessions were planned as low-intensity sessions targeted to heart rate zone 1 for a duration of 80–120 min. Morning sessions were planned as 100–120 min and evening sessions 80–100 min. Post-training analysis indicated that these sessions also contained small portions of zone 2 and zone 3 intensities due to short uphill segments of the course. Two-morning sessions (on the 3rd and 5th day) were planned as high-intensity interval sessions in zone 3 intensity according to a polarized model (Seiler and Kjerland, 2006; Stöggl and Sperlich, 2014). The first session included 3 × 3 min at maximal effort with a 3-minute recovery and the second session 8 × 300 m maximal effort with a 1.5-minute recovery. All athletes underwent the same training program with the same relative intensity based on heart rate zones provided individually, but with the same absolute duration.

In Paper III the 1st week of the study was characterized as the baseline week, for the athletes to adapt to the training environment, without an increase in training load compared to previous weeks. During the next two weeks, training volume was increased two times compared to the baseline week and the 4th week was organized as a recovery week where training volume was planned to decrease about 30% of the high-volume weeks.

4.2.4. Internal training load

To record the internal training load, athletes were instructed how to use an online training log and sports coaching software Sportlyzer (Sportlyzer OÜ, Tartu, Estonia) for recording all the training sessions during three study periods. These parameters included the mode of training, duration of each training session and the RPE on a 10-pt scale (Table 1).

In Studies II and III, heart rate was recorded using heart rate monitors (Polar M400, Polar Oy, Kempele, Finland) during every training session. All individual training sessions were downloaded to quantify training intensity distribution based on the time-in-zone method using the VT1 and VT2 as anchor points to discriminate between the three zones. Total weekly time in each of the three training zones was calculated.

The post-session RPE was recorded 30 min after the end of each training session with the value from 0 to 10 (Table 1), by answering the question: "How hard was your workout?" All the participants were familiar with the RPE scale before the study as they have been using it during their previous training routine. Internal training load was determined by the sRPE method – RPE multiplied by the duration (min) of the session (Foster et al., 2001). The 10-pt RPE responses were further used to categorize training sessions as either *Easy*, *Moderate* or *Hard*. For consistency in terminology, some changes in RPE categorization were made in the dissertation. In the original manuscript of Paper I the *Easy* sessions were named *Light*, however, due to harmonization purposes, *Light* is named *Easy* in the current dissertation. Training load categories in the original manuscript of Paper III (sRPE1, sRPE2, sRPE3, respectively) are used as $sRPE_{Easy}$, $sRPE_{Mod}$, $sRPE_{\mathit{Hard}}$ in this dissertation, respectively.

In Paper I, the 10-pt scale was categorized to either *Easy*, *Moderate* or *Hard* session according to three different quantification methods and the corresponding sRPE was calculated based on the length of the training. Quantification of the internal load was done as follows. Firstly, the categorization method used by Seiler & Kjerland (2006) (sRPE.S) where values 0–4 indicated *Easy*, 5–6 *Moderate* and 7–10 *Hard* sessions ($sRPE.S_{Easy}$, $sRPE.S_{Mod}$, $sRPE.S_{Hard}$, respectively). The second method was based on Wallace et al (2009) (sRPE.W) where values 0–2, 3–5 and 6–10 indicated internal training load of *Easy* ($sRPE.W_{Easy}$), *Moderate* ($sRPE.W_{Mod}$) and *Hard* sessions ($sRPE.W_{Hard}$), respectively. Thirdly, we used individual RPE responses (sRPE.I) to calculate internal load from the incremental test where RPE values at intensities lower than VT1 were used to calculate *Easy* ($sRPE.I_{Easy}$), values between VT1 and VT2 as *Moderate* ($sRPE.I_{Mod}$) and values higher than VT2 as *Hard* sessions ($sRPE.I_{Hard}$). Detailed categorization of internal load is described in Table 3. Internal training load from the respective categories (*Easy*, *Moderate*, *Hard*) indicates the cumulative training load from each category.

Table 3. Categorization of internal training load to *Easy, Moderate* or *Hard* based on RPE scale.

Reference	Method	Easy	Moderate	Hard
Seiler & Kjerland (2006)	sRPE.S	RPE ≤ 4 $sRPE.S_{Easy}$	RPE 5–6 $sRPE.S_{Mod}$	RPE ≥ 7 $sRPE.S_{Hard}$
Wallace et al. (2009)	sRPE.W	RPE ≤ 2 $sRPE.W_{Easy}$	RPE 3–5 $sRPE.W_{Mod}$	RPE ≥ 6 $sRPE.W_{Hard}$
Individual	sRPE.I	≤ RPE VT1 $sRPE.I_{Easy}$	> RPE VT1 & < RPE VT2 $sRPE.I_{Mod}$	≥ RPE VT2 $sRPE.I_{Hard}$

RPE – rating of perceived exertion; VT – ventilatory threshold; sRPE.S – Seiler & Kjerland (2006) based zone distribution; sRPE.W – Wallace et al (2009) based zone distribution; sRPE.I – individual VT1 and VT2 zone distribution determined during incremental testing; Mod – moderate

In Paper II, post-exercise RPE responses were used to categorize training sessions as either *Easy*, *Moderate* or *Hard* according to the individual method used in Study I. Individual RPE quantification was done during the incremental test to match the perception of effort to VT intensities, where mean RPE values of 4.3 ± 1.1 at VT1 and 6.9 ± 1.3 for VT2 were found. These RPE markers were used to describe individual *Easy* sessions (RPE value <VT1), individual *Moderate* sessions (RPE values between VT1 and VT2) and individual *Hard* sessions (RPE values >VT2). Those anchor points were individual to each athlete and were used to match the effort of training. For example, a 60 min session below aerobic threshold intensity could be rated as "*Easy*" if the athlete responded 3 on the RPE scale or rated as "*Hard*" if an athlete reported 7, depending on the ability to sustain a specific duration. Based on the median rating of RPE, the subjects were divided into either low (G_{low}) or high (G_{high}) training load groups. High-intensity sessions were excluded for grouping.

In Paper III, post-exercise RPE responses were used to categorize training sessions by effort, to describe the entire session as either *Easy* ($sRPE_{Easy}$), *Moderate* ($sRPE_{Mod}$) or *Hard* ($sRPE_{Hard}$) using VT1 and VT2 cut-off points as previously indicated (Seiler & Kjerland, 2006). Heart rate and RPE from strength sessions were not included for analysis.

4.2.5. Specific performance tests (Paper I and II)

In Paper I swimming performance was measured within 48 hrs after the incremental test. 100-m freestyle was performed during the local competitions, and 100-m freestyle with leg-kick only was performed during the first training session of the 10-week period. This test was performed within the following 48 hrs after the competition. The time of the 100-m performance tests was measured in the pool using contact plates. The same swimming performance tests were conducted after the 10-week study period, where 100-m freestyle was performed during National Championships and 100-m freestyle leg-kick only was performed during the training session.

In Paper II double poling performance test (maximal power output per bodyweight – $W_{max/kg}$) on a ski ergometer was conducted at the beginning and at the end of the 1-week training camp. Post testing was performed 2 to 3 days after the last training session. Both tests were performed until volitional exhaustion or until the subject could not hold the requested power for 5 consecutive pulls.

4.2.6. Ratings of *fatigue* and *will to train (*Paper II)

In Paper II all subjects rated subjectively the levels of *fatigue* and *will to train* on a 10-pt Likert-type scale, where 1 indicated “no fatigue at all,” or “no will to train at all”. Option 10 indicated “maximal fatigue”, or “highest will to train”. In both cases, it was a numerical rating scale without verbal descriptors in the middle section, indicated as a visual analogue scale. Subjective ratings were collected during the first two days, in the middle and during the last two days of the training camp. The ratings were asked in the morning before the first training session.

4.2.7. RESTQ-Sport questionnaire (Paper III)

The RESTQ-Sport questionnaire was used in Paper III. RESTQ-Sport is a psychometric instrument that can be used to measure individuals for stress and recovery. The instrument consists of 77 items (19 scales with four items each plus one warm-up item). A Likert-type scale is used with values ranging from 0 (never) to 6 (always) indicating how often the respondent participated in various activities during the past 3 days/nights. The first seven scales cover different aspects of subjective strain as well as the resulting consequences (see Table 8). The next 5 scales are the basic scales for the recovery area *with Success* as the only resulting recovery-oriented scale concerned with performance in general but not in a sport-specific context (Kellmann and Günther, 2000). Sport-specific details of stress and recovery are examined in scales 13 to 19 (Kellmann and Günther, 2000; Kellmann and Kallus, 2001). The Estonian version of the questionnaire (Mäestu et al., 2006) was implemented every Monday starting after the baseline week of the training camp. Therefore, it was implemented four times – after every week (1st, 2nd, 3rd, and 4th) of the training camp. Participants completed the questionnaire always after breakfast to keep the time schedule comparable.

4.3. Statistical analysis

Descriptive statistics of the subjects are presented as mean values and standard deviations (SD). Before analyses, the assumption of normality was assessed by using the Shapiro-Wilks test.

In Paper I differences between physiological and performance variables after a 10-week training period were assessed with a paired-sample T-test. Standardized effect size (ES) is reported as Cohen *d*, using the pooled SD as the denominator. Inferences about the true effect are based on the width of the confidence interval (CI) relative to the smallest worthwhile change (SWC, 0.2 × standardized effect) (Hopkins et al., 2009). Dose-response relationships between measures of internal training load and fitness or swimming performance variables were determined using Pearson product-moment correlation coefficients. Uncertainties in the correlation coefficients are presented as 95% Cls.

In Paper II differences in the variables during the 1-week training period were assessed using the Bayesian Independent-Sample Inference procedure, and it was used to control the differences between groups (testing Hypothesis 1 against Hypothesis 0) indicating weak (BF_{10}=1–3), moderate (BF_{10}=3–10), strong (BF_{10}=10–30) or very strong (BF_{10}>30). Within-group $W_{max/kg}$ before and after training camp was assessed using Bayesian Paired Samples t-test. Bayesian Analysis of Covariance (ANCOVA) was used to adjust relative maximal performance change after training camp against high-intensity training sessions performed during the training camp. In this model, a high-intensity training load was inserted as the covariate. Standardized ES is reported as Hedges' *g* due to the sample size being lower than 20 using the pooled and weighted SD as the denominator. The magnitude of difference (ES) was classified as small (ES<0.2), medium (0.2≤ ES <0.5), large (0.5≤ ES <0.8), or very large (ES≥0.8) (Hopkins et al., 2009). The subjective ratings change in *fatigue* and *will to train* (as within-subject factors) in G_{low} and G_{high} groups (as between-subject factors) during training camp was assessed using repeated measures of ANOVA.

In Paper III repeated measures of ANOVA was used to test for mean differences between the four timepoints for measured parameters with Bonferroni adjustment. Two-way repeated measures of ANOVA were used to test the interaction between the time and quantification method. In addition, differences between heart rate and sRPE distribution (%) at different timepoints (HR Z1, HR Z2, HR Z3) and training loads ($sRPE_{Easy}$, $sRPE_{Mod}$, $sRPE_{Hard}$) were assessed with a paired-sample t-test. An automatic linear modelling was carried out to explore the main predictors of the *fatigue* score of the RESTQ-Sport questionnaire. The variables inserted into the model as independent variables were training volume, distance, total training load, $sRPE_{Easy}$, $sRPE_{Mod}$, $sRPE_{Hard}$, HR Z1, HR Z2 and HR Z3.

The level of significance was set at $P<0.05$ for all tests.

5. RESULTS

5.1. Relationships with sRPE based training load and performance (Paper I)

A total of 497 swimming training sessions of 8 participants were analysed during the 10-week period. Overall, easy, moderate, and hard internal training load distributions using three different quantification methods are presented in Figure 1.

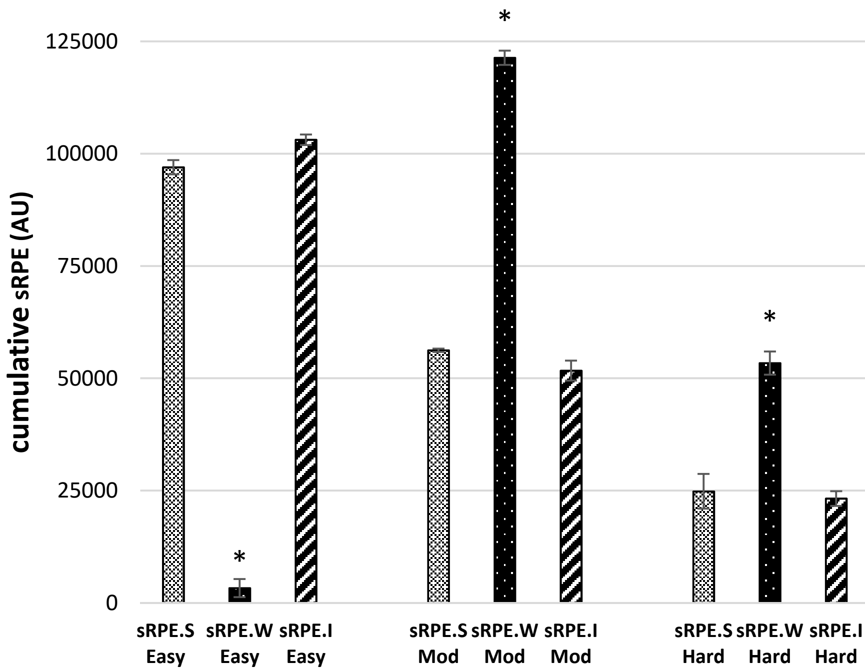

Figure 1. Cumulative training load using 3 different sRPE categorizations in adolescent swimmers during the 10-week training period. AU – arbitrary unit; sRPE – session rating of perceived exertion; sRPE.S – Seiler & Kjerland (2006) based distribution; sRPE.W – Wallace et al (2009) based distribution; sRPE.I – individual VT1 and VT2 based distribution determined during incremental testing; Mod – moderate; * – significantly different from Seiler & Kjerland (2006) and individual-based zone distribution at the 0.05 level.

During the 10-week training period there was a moderate increase in $\dot{V}O_{2max}$ (+8.2%, P=0.002, ES=1.13) and small, but an insignificant increase in $W_{max/kg}$ (+1.5%, P=0.685, ES=0.27). A very large increase was found in anaerobic threshold $W \cdot kg^{-1}$ (+8.8%, P=0.001; ES=2.46) and large increase in aerobic threshold $W \cdot kg^{-1}$ (+7.2%, P=0.007; ES=1.58). Small improvements (ES=0.36) in 100-m freestyle swimming time (-3.1%; P=0.001) and 100-m freestyle with leg-kick only (-4.0%; P=0.039; ES=0.40) were observed following the training period (Table 4).

Overall internal training load during the 10-week period was associated with the improvement in anaerobic threshold (r=0.81; P<0.05; Table 5). Also, $sRPE.S_{Mod}$ was significantly related to the improvement in anaerobic threshold (r=0.78). Changes in $\dot{V}O_{2max}$ during the 10-week period were negatively related to $sRPE.I_{Easy}$ (r=-0.77) and positively to $sRPE.I_{Hard}$ (r=0.77). $sRPE.I_{Hard}$ was also associated with the improvements in 100-m leg-kick only performance (r=0.76; P<0.05) and a tendency (P<0.1) towards the improvement of 100-m freestyle performance was found. Training load categorization based on Wallace et al. (2009) did not have any associations with changes in performance variables. During the 10-week period, the height of the subjects changed significantly (P=0.009), therefore we also corrected the regression models against changes in height, but as it did not change the results, uncorrected models are presented.

Table 4. Physiological and performance measures before and after the 10-week training period before the competition in adolescent swimmers.

Variable	Before 10-weeks	After 10-weeks	Mean difference [95% CI]	Effect size [95% CI]	Qualitative outcome
Incremental test variables	Mean ± SD	Mean ± SD			
$\dot{V}O_{2max}$ ($ml \cdot min^{-1} \cdot kg^{-1}$)	51.0 ± 3.2	**55.2 ± 4.2***	4.2 [1.4, 6.8]	1.13	Moderate effect
$W_{max/kg}$ ($W \cdot kg^{-1}$)	3.96 ± 0.10	4.02 ± 0.30	0.06 [-0.27; 0.38]	0.27	Small effect
AeT $W \cdot kg^{-1}$	2.09 ± 0.10	**2.24 ± 0.09***	0.15 [0.06; 0.24]	1.58	Large effect
AnT $W \cdot kg^{-1}$	3.30 ± 0.09	**3.59 ± 0.14***	0.29 [0.18; 0.39]	2.46	Very large effect
Swimming variables					
100-m freestyle swimming time	58.5 ± 5.0	**56.7 ± 5.0***	-1.8 [-2.5; -1.0]	0.36	Small effect
100-m swimming time leg-kick only	86.6 ± 10.2	**83.1 ± 7.3***	-3.5 [-6.8; -0.2]	0.40	Small effect

CI – confidence interval; $\dot{V}O_{2max}$ – maximal oxygen consumption; $W_{max/kg}$ – maximal power output; AeT – aerobic threshold; AnT – anaerobic threshold; * – The statistical differences ($P<0.05$) are shown in bold.

Table 5. Relationships (unstandardized coefficients (B) and confidence intervals [95% CI]) between training load measures and % changes in physiological and performance levels.

	%Δ AeT W·kg^{-1}	**%Δ AnT W·kg^{-1}**	**%Δ $\dot{V}O_{2max}$ (ml·min^{-1}·kg^{-1})**	**%Δ 100-m freestyle swimming time**	**%Δ 100-m swimming time leg-kick only**
Cumulative sRPE	0.16 [-0.94; 1.25]	**0.81* [0.12; 1.43]**	-0.42 [-1.41; 0.60]	0.17 [-0.82; 1.15]	-0.13 [-1.12; 0.86]
sRPE.S_{Easy}	-0.23 [-1.60; 1.06]	-0.04 [-1.41; 1.32]	-0.68 [-1.81; 0.17]	-0.43 [-1.33; 0.47]	0.01 [-0.99; 1.00]
sRPE.S_{Mod}	0.35 [-0.73; 1.44]	**0.78* [0.05; 1.52]**	-0.04 [-1.20; 1.12]	0.51 [-0.73; 1.21]	0.22 [-1.25; 0.66]
sRPE.S_{Hard}	0.02 [-1.15; 1.18]	0.47 [-0.56; 1.50]	-0.07 [-1.23; 1.09]	0.51 [-0.35; 1.37]	0.24 [-0.75; 1.20]
sRPE.W_{Easy}	0.05 [-1.17; 1.27]	-0.39 [-1.54; 0.71]	0.13 [-1.08; 1.34]	-0.52 [-1.37; 0.34]	0.28 [0.03; 1.41]
sRPE.W_{Mod}	-0.08 [-1.14; 0.99]	0.34 [-0.69; 1.32]	-0.66 [-1.42; 0.19]	-0.23 [-1.20; 0.74]	-0.45 [-1.34; 0.45]
sRPE.W_{Hard}	0.23 [-0.84; 1.26]	0.67 [-0.18; 1.43]	0.01 [-1.07; 1.08]	0.43 [-0.47; 1.33]	0.06 [-0.94; 1.05]
sRPE.I_{Easy}	-0.18 [-1.31; 0.94]	0.51 [-0.48; 1.49]	**-0.77* [-1.50; -0.03]**	0.19 [-0.79; 1.17]	-0.32 [-1.26; 0.63]
sRPE.I_{Mod}	0.20 [-0.99; 1.42]	-0.01 [-1.24; 1.23]	0.26 [-0.91; 1.47]	-0.34 [-1.28; 0.61]	-0.13 [-1.12; 0.86]
sRPE.I_{Hard}	0.39 [-0.67; 1.43]	0.50 [-1.08; 1.18]	**0.77* [0.03; 1.48]**	0.68 [-0.01; 1.28]	**0.76* [0.11; 1.41]**

AeT – aerobic threshold; AnT – anaerobic threshold; $\dot{V}O_{2max}$ – maximal oxygen consumption; sRPE – session rating of perceived exertion; sRPE.S – Seiler & Kjerland (2006) based zone distribution; sRPE.W – Wallace et al (2009) based zone distribution; sRPE.I – individual VT1 and VT2 zone distribution determined during incremental testing; Mod – moderate; * – The statistical relationships ($P<0.05$) are shown in bold.

5.2. Different RPE during similarly prescribed sessions (Paper II)

There were no differences between the anthropometrical and physiological parameters in both, high and low training load groups (P≥0.05; Table 6), except for heart rate at VT2, which was significantly higher in G_{high} (P<0.05). However, if heart rate values were expressed as a percentage of maximal heart rate no differences between the groups were found for VT1 and VT2 (data not shown; P≥0.05). Similarly, while comparing aerobic threshold $W \cdot kg^{-1}$ and anaerobic threshold $W \cdot kg^{-1}$ determined during the incremental test there were no differences between the groups (P≥0.05).

Table 6. Main characteristics (mean ± SD) of the XC skiers in two different groups based on the RPE ratings during training sessions.

	G_{low} (n=6)	G_{high} (n=7)	BF_{10}	95% CI for BF_{10}	P-value
Age (y)	13.4 ± 2.0	13.4 ± 1.9	0.457	-0.888 to 0.842	0.970
Body mass (kg)	47.8 ± 10.3	49.7 ± 9.3	0.475	-1.012 to 0.731	0.739
Height (m)	1.62 ± 0.14	1.55 ± 0.10	0.619	-0.512 to 1.327	0.349
$\dot{V}O_{2max}$ ($ml \cdot min^{-1} \cdot kg^{-1}$)	54.1 ± 4.2	48.8 ± 9.8	0.733	-0.435 to 1.465	0.245
HR VT1 (BPM)	153.7 ± 5.8	156.4 ± 5.4	0.587	-1.277 to 0.542	0.396
HR VT2 (BPM)	173.8 ± 7.6	182.6 ± 5.2	2.418	-2.234 to 0.092	**0.031***
HR_{max} (BPM)	188.0 ± 8.9	197.1 ± 7.2	1.552	-1.970 to 0.200	0.064

G_{low} – subjects (1 girl, 5 boys) who rated their low-intensity trainings lower than median RPE of the whole group ratings; G_{high} – subjects (3 girls, 4 boys) who rated their low-intensity trainings higher than median RPE; BMI – body mass index; $\dot{V}O_{2max}$ – maximal oxygen consumption; HR VT1 – heart rate values at VT1 determined during the first incremental test; HR VT2 – heart rate values at VT2 determined during the first incremental test; HR_{max} – heart rate maximum achieved during the incremental test; BPM – beats per minute; BF_{10} – Bayesian factor in favour H_1 over H_0, CI – confidence interval. * – The statistical differences (P<0.05) are shown in bold.

Total training time during the 1-week period was 16.3 ± 0.8 hrs for G_{low} and 16.0 ± 0.6 hrs for G_{high}, including 3.2 ± 0.7 hrs and 2.9 ± 0.7 hrs of high-intensity training sessions for G_{low} and G_{high}, respectively (P≥0.05). After excluding high-intensity training sessions and dividing subjects into two groups, the average RPE rating during training sessions was 3.09 ± 0.34 in G_{low} compared to 4.94 ± 1.07 in G_{high} (P=0.000). G_{low} had a higher number of sessions rated as individual *Easy*, as well as a lower number of both – sessions rated as individual *Moderate* and individual *Hard*, compared to G_{high} group (P<0.05) although these sessions were all prescribed in zone 1. However, no significant differences were found in time spent in different heart rate zones during low-intensity trainings between the two groups (Table 7).

Table 7. Categorization of session ratings and time spent in different heart rate zones during the low-intensity trainings between low and high RPE groups of young XC skiers.

	(mean ± SD)		**Mean Rank score**				
	G_{low} (n=6)	**G_{high} (n=7)**	**G_{low} (n=6)**	**G_{high} (n=7)**	**BF_{10}**	**95%CI for BF_{10}**	**Sig.**
No. of sessions rated as *Easy*	8.8 ± 0.4	4.0 ± 2.6	10.42	4.07	18.294	0.371, 3.371	**0.002***
No. of sessions rated as *Mod*	0.2 ± 0.4	1.9 ± 2.0	4.83	8.86	2.457	2.244, 0.088	**0.042***
No. of sessions rated as *Hard*	0.0 ± 0.0	3.1 ± 2.9	4.50	9.14	0.927	-1.637, 0.348	**0.014***
HR Z1 (min)	517.0 ± 185.0	474.4 ± 132.1	6.67	6.33	0.500	-0.708, 1.098	0.873
HR Z2 (min)	149.3 ± 135.2	213.0 ± 91.2	5.67	7.33	0.623	-1.358, 0.536	0.423
HR Z3 (min)	25.9 ± 46.3	25.1 ± 29.2	6.50	6.50	0.467	-0.874, 0.905	0.998

RPE – rating of perceived exertion; G_{low} – subjects who rated their low-intensity trainings lower than median RPE of the whole group ratings; G_{high} – subjects who rated their low-intensity trainings higher than median RPE; Mod – moderate; HR Z1 – heart rate values below ventilatory threshold 1; HR Z2 – heart rate values between ventilatory threshold 1 and 2; HR Z3 – heart rate values above ventilatory threshold 2; BF_{10} – Bayesian factor in favour H_1 over H_0, CI – confidence interval. * – The statistical differences ($P<0.05$) are shown in bold.

Total internal load (sRPE) in G_{low} was 3848 ± 608 arbitrary units (AU) while it was significantly higher in G_{high} (5063 ± 1089 AU; P=0.034). Similarly, accumulated internal load in low-intensity sessions was significantly higher in G_{high} compared to G_{low} (4010 ± 765 AU and 2499 ± 193 AU, respectively; P=0.001; BF_{10}=39.16), while no differences were found in internal load between high-intensity sessions (1053 ± 499 AU and 1349 ± 595 AU, respectively; P=0.351; BF_{10}=0.62; Figure 2).

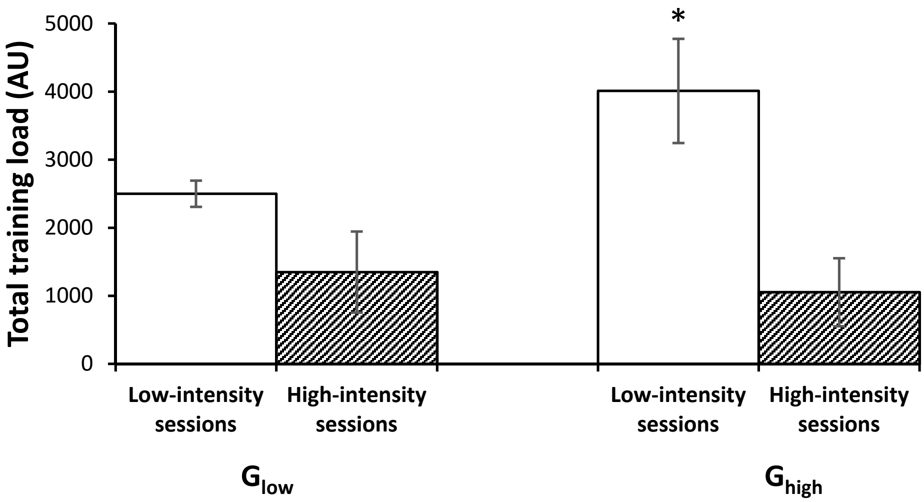

Figure 2. Total internal load (AU) during low- and high-intensity trainings between two groups. G_{low} – subjects who rated their low-intensity trainings lower than median RPE of the whole group ratings; G_{high} – subjects who rated their low-intensity trainings higher than median RPE; * – significantly different from G_{low} low-intensity trainings at the 0.05 level.

There were no differences in $W_{max/kg}$ at the beginning (P=0.257, BF_{10}=0.714) or at the end of the study (P=0.220; BF_{10}=0.772). In both groups performance increased significantly (P<0.05) however, after 1-week training period there was a large effect (ES=0.67; 95% CI for ES 0.15 – 0.39) in $W_{max/kg}$ (pre: 2.44 ± 0.41, post 2.71 ± 0.31; +12.5%; P=0.005; BF_{10}=12.47) for G_{high}, while a medium effect (ES=0.32; 95% CI for ES 0.12–0.38) was found for G_{low} (before: 2.84 ± 0.77, after: 3.09 ± 0.71; +10.7%; P=0.014; BF_{10}=5.32) (Figure 3). After adjusting results for internal load from the high-intensity session, the effect of the change for $W_{max/kg}$ increased to very large (ES=1.82; 95% CI for ES 0.56–1.00; BF_{10}=80.32) in G_{high}, while in G_{low} the effect of the change remained medium (ES=0.22; 95% CI for ES -0.41–0.71; BF_{10}=0.42).

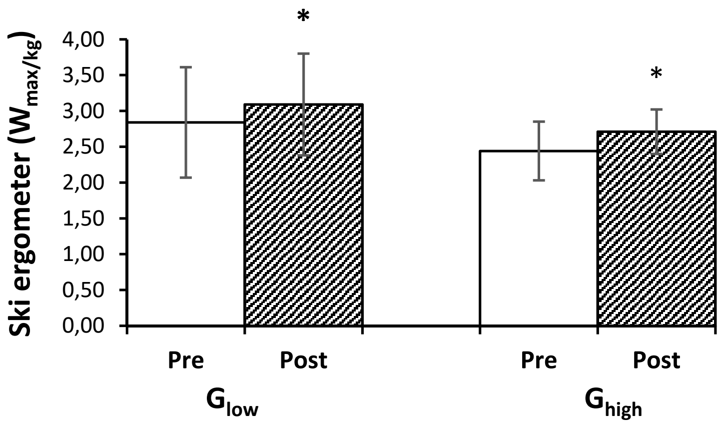

Figure 3. Performance changes on incremental double poling ski ergometer test before and after the 1-week training camp in young XC skiers. G_{low} – subjects who rated their low-intensity trainings lower than median RPE of the whole group ratings; G_{high} – subjects who rated their low-intensity trainings higher than median RPE; * – significantly different from pre-test at 0.05 level.

The subjective ratings of *fatigue* and *will to train* were not significantly different between both groups during the whole training camp (P≥0.05) (Figure 4). Furthermore, there were no within days differences between groups for both, *fatigue* and *will to train* indices (P≥0.05). However, a within-subject test showed that there was a significant time effect, indicating that in both groups *fatigue* increased (F=3.238; P=0.035), while *will to train* decreased (F=5.591; P=0.004) during training camp period.

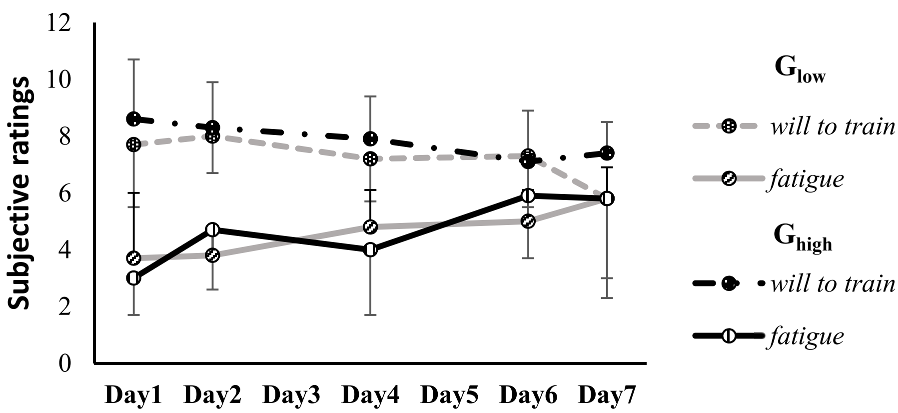

Figure 4. Changes in the subjective ratings of *fatigue* and *will to train* during the 1-week training camp in young XC skiers. G_{low} – subjects who rated their low-intensity trainings lower than median of the whole group ratings; G_{high} – subjects who rated their low-intensity trainings higher than median

5.3. Associations between fatigue and internal training load (Paper III)

Total training volume during the 4-week training period in high-level rowers was 58.3 ± 8.8 hrs (Figure 5). Training volume significantly changed over time ($F_{(3,54)}$=57.927, P<0.001). Furthermore, training volume was doubled from 522.5 ± 198.5 min in the baseline week to 1096.6 ± 187.9 min in week 2 (P<0.001). The highest training volume was achieved during week 3 with 1121.7 ± 268.6 min of training and then decreased (P<0.001) to 755.8 ± 82.7 min during the recovery week as planned for the 4 micro-cycles. The increase in training volume was the result of the number of the training sessions that changed significantly ($F_{(3,54)}$=26.703; P<0.001) and resulted in an increase from baseline (9.1 ± 2.7) to week 2 and 3 (15.8 ± 4.4 and 15.9 ± 4.7, respectively). There was a significant change in the average length of training sessions over four timepoints ($F_{(3,54)}$=5.460, P=0.006), with a significant increase from 64.0 ± 21.3 min at baseline to approximately 75.5 min both in week 2 and 3 (P<0.05) and a significant decrease to 61.7 ± 12.8 min in week 4 (P<0.05). No changes were found for the volume of strength and flexibility trainings during weeks 1–3, but a significant decrease in week 4 (P<0.05), compared to all previous weeks was found.

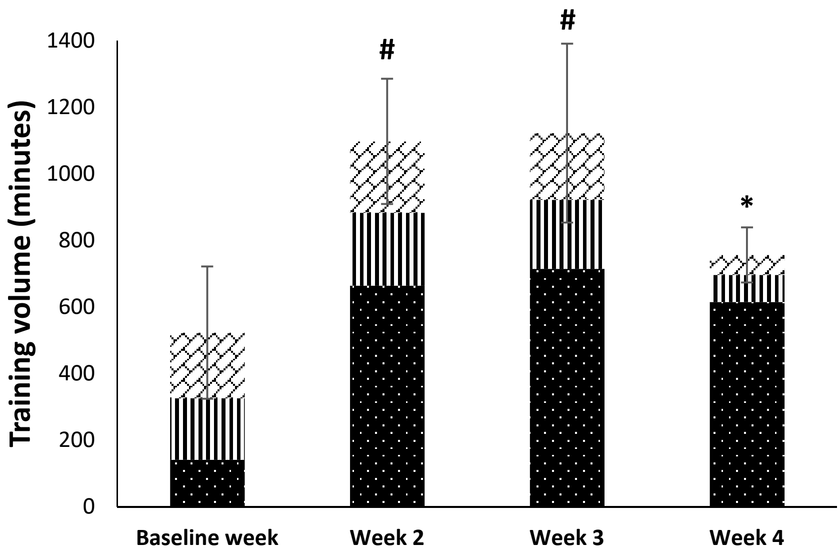

Figure 5. Total training volume (minutes) and the volumes of each training type during the 4-week training period. Specific endurance includes indoor rowing (ergometer) and outdoor rowing. Other endurance includes all types of other endurance sports – mostly running and cycling; * – significantly different total training volume from baseline week (P<0.05); # – significantly different total training volume from baseline week and week 4 (P<0.05).

Accumulated training load (sRPE) during the 4-week training period was 12388 ± 3190 AU. There was an overall change in weekly internal training load over the four timepoints ($F_{(3,54)}$=42.711, P<0.001). In addition, the weekly internal load was significantly different (P<0.05) between all training weeks except between the 2nd and 3rd week (P=0.845). Training session categorization according to heart rate (Z1, Z2 and Z3) and effort-based methods ($sRPE_{Easy}$, $sRPE_{Mod}$ and $sRPE_{Hard}$) can be found in Figure 6. About 80% of sessions were performed within HR Z1 below VT1 and only about 5% of sessions in HR Z3. Although the heart rate distribution within the zones did not change during the 4-weeks, the subjective rating of internal load (sRPE) presented a significant shift from low to moderate and high load (subjective strain) during weeks 2 and 3, which resulted in a significant change in $sRPE_{Mod}$ over the study period ($F_{(3,54)}$=2.881; P=0.044). No other changes over time were found for different zones.

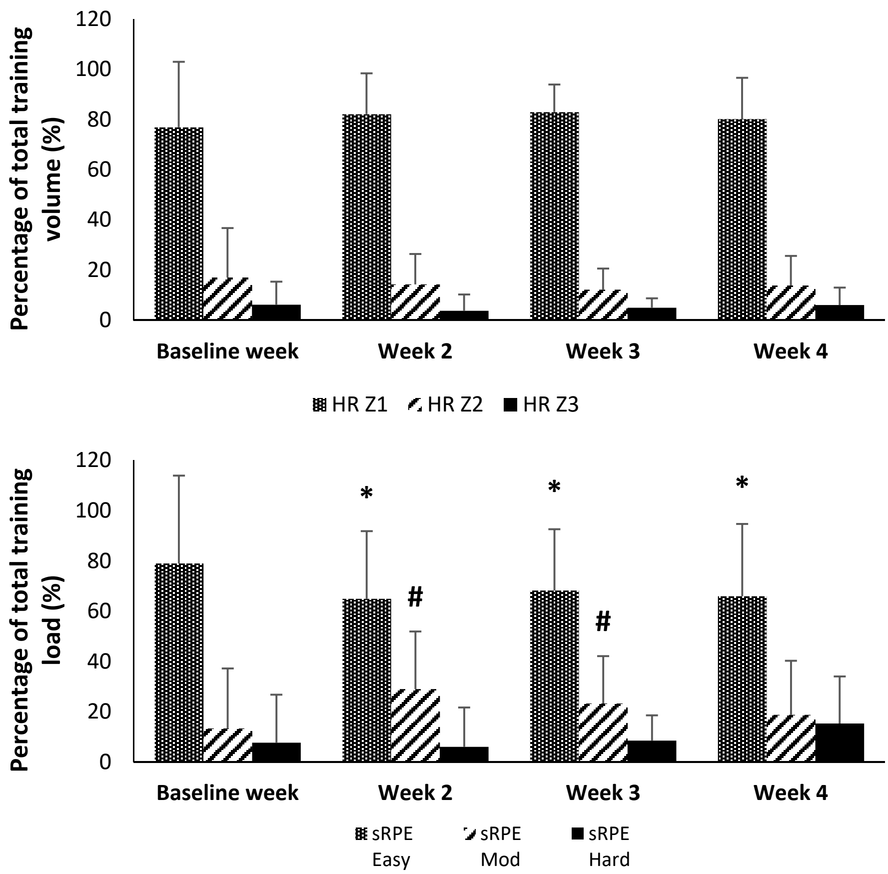

Figure 6. Differences between the percentages (%) in heart rate zone distributions (HR Z1, HR Z2, HR Z3; upper panel) and the respective effort-based zone distributions ($sRPE_{Easy}$, $sRPE_{Mod}$, $sRPE_{Hard}$; lower panel) during the 4-week training period; * – significantly different from HR Z1 P<0.05; # – significantly different from HR Z2 (P<0.05).

There was significant time x quantification method interaction in HR Z1 vs $sRPE_{Easy}$ ($F_{(3,51)}$=3.970; P=0.013) and in HR Z2 vs $sRPE_{Mod}$ ($F_{(3,51)}$=0.906; P=0.045). The respective distributions of the three zones were not different in the baseline week if comparing the heart rate and RPE quantification methods (P≥0.05). However, the distribution of $sRPE_{Easy}$ was lower compared to HR Z1 in weeks 2–4 (P<0.05) and $sRPE_{Mod}$ was higher in weeks 2–3 compared to HR Z2 (P<0.05). No time x quantification method interaction in HR Z3 vs $sRPE_{Hard}$ ($F_{(3,51)}$=0.906; P=0.445) was found. However, in week 4, there was a tendency (P=0.06) for a higher $sRPE_{Hard}$ compared to HR Z3.

If applying a zone distribution according to an 80:20 principle (Seiler, 2010), the proportion of $sRPE_{Mod}$ + $sRPE_{Hard}$ trainings did not change over time ($F_{(3,54)}$=1,379, P=0.260), but a tendency (P=0.080) for an increase was found between baseline week and week 4 (from 21.0% to 34.1%, respectively).

Significant increases (P<0.05) during the 4-weeks were found in the following stress scales: *Social Stress, Conflicts/Pressure, Fatigue, Physical Complaints, Disturbed Breaks and Injury* (Table 8). In Recovery scales, changes between the weeks (P<0.05) were found for *General Well-Being, Sleep Quality, Personal Accomplishments* and *Self-Regulation.* Most of the changes in the scales appeared in the two final weeks (week 3 and week 4) of the study. During the final week significant increases were mostly found in the Stress scales – *Social Stress* (P=0.046, week 2 and week 4), *Conflicts/ Pressure* (P=0.025, week 2 and week 4), *Fatigue* (P=0.046, week 2 and week 4), *Physical Complaints* (P=0.011, baseline week and week 4), *Disturbed Breaks* (P=0.021, week 2 and week 4). In contrast, significant decreases were found in the following recovery scales during the final week of the study period – *General Well-Being* (P=0.048, between baseline week and week 4*)* and *Self-Regulation* (P=0.022, between week 2 and week 4).

Table 8. Average scores (mean ± SD) of the Recovery-Stress Questionnaire for Athletes (RESTQ-Sport) scales during the 4-week training period.

Scale	Baseline week	Week 2	Week 3	Week 4	P-value
General stress					
1. General Stress	1.01 ± 0.93	1.03 ± 1.08	1.25 ± 1.03	1.97 ± 1.68	ns
2. Emotional Stress	1.21 ± 0.90	1.13 ± 1.10	1.28 ± 0.88	2.09 ± 1.58	ns
3. Social Stress	1.29 ± 0.82	1.11 ± 0.94	1.33 ± 0.91	**2.25 ± 1.38**[b]	P<0.05
4. Conflicts/Pressure	1.65 ± 0.90	1.61 ± 0.87	1.93 ± 0.71	**2.59 ± 1.19**[b]	P<0.05
5. Fatigue	1.74 ± 1.19	1.61 ± 1.11	**2.07 ± 1.23**[b]	**2.69 ± 1.50**[b]	P<0.05
6. Lack of Energy	1.81 ± 0.82	1.53 ± 0.69	1.70 ± 0.73	1.75 ± 0.53	ns
7. Physical Complaints	1.44 ± 0.75	1.52 ± 0.83	1.68 ± 0.64	**1.91 ± 0.58**[a]	P<0.05
General recovery					
8. Success	3.11 ± 0.79	2.75 ± 1.25	2.55 ± 0.92	2.75 ± 0.88	ns
9. Social Recovery	3.57 ± 1.36	3.42 ± 1.35	3.47 ± 1.31	2.50 ± 1.20	ns
10. Physical Recovery	3.18 ± 1.18	3.08 ± 1.08	2.83 ± 1.07	2.34 ± 1.18	ns
11. General Well-Being	3.96 ± 1.32	3.94 ± 1.31	3.93 ± 1.27	**2.69 ± 1.27**[a]	P<0.05
12. Sleep Quality	4.00 ± 1.08	**4.53 ± 0.90**[a]	4.15 ± 1.13	3.31 ± 1.46	P<0.05
Sport stress					
13. Disturbed Breaks	1.47 ± 0.82	1.09 ± 0.50	**1.63 ± 0.93**[b]	**1.94 ± 0.94**[b]	P<0.05
14. Emotional Exhaustion	1.07 ± 1.36	1.03 ± 1.14	1.30 ± 1.31	1.69 ± 1.93	ns
15. Injury	2.13 ± 0.98	2.19 ± 1.03	**2.03 ± 0.92**[b]	1.63 ± 0.82	P<0.05
Sport recovery					
16. Being in Shape	3.51 ± 1.11	3.39 ± 1.24	3.00 ± 1.09	2.84 ± 0.88	ns
17. Personal Accomplishments	3.19 ± 0.99	2.88 ± 1.14	**2.50 ± 1.29**[a]	**2.22 ± 1.48**[a]	P<0.05
18. Self-Efficacy	3.44 ± 0.76	3.41 ± 0.98	3.03 ± 1.00	3.25 ± 0.96	ns
19. Self-Regulation	2.31 ± 0.83	2.47 ± 0.88	2.37 ± 0.94	**3.44 ± 1.24**[b]	P<0.05

[a] – P<0.05 is significantly different from baseline week; [b] – P<0.05 is significantly different from week 2; ns – non-significant. The statistical differences (P<0.05) are shown in bold.

According to the automatic linear modelling, three important predictors of RESTQ-Sport scale *Fatigue* were found: overall training load (sRPE), $sRPE_{Hard}$ and $sRPE_{Mod}$ (Table 9). $sRPE_{Hard}$ and $sRPE_{Mod}$ were associated positively with *Fatigue* while negative associations were found for sRPE (Table 9). No relationships with *Fatigue* were found for heart rate-based quantification zones.

Table 9. An automatic linear modelling to indicate the main predictors of *Fatigue* scale levels.

Model term	Coefficients	SE	P-value	Importance
Intercept	2.724	0.470	<0.001	
Training volume (min)	0.003	0.002	0.121	0.078
Training distance (km)	0.001	0.004	0.784	0.002
sRPE (AU)	-0.002	0.001	**0.007***	0.251
$sRPE_{Easy}$ (AU)	0.001	0.001	0.279	0.037
$sRPE_{Mod}$ (AU)	0.002	0.001	**0.011***	0.219
$sRPE_{Hard}$ (AU)	0.002	0.001	**0.008***	0.239
HR Z1 (min)	-0.002	0.001	0.193	0.054
HR Z2 (min)	0.001	0.003	0.735	0.004
HR Z3 (min)	-0.015	0.008	0.089	0.116

SE – standard error; AU – arbitrary unit; sRPE – session rating of perceived exertion; $sRPE_{Easy}$ – internal load of training sessions rated as 4 or less on a 10-pt RPE scale; $sRPE_{Mod}$ – internal load of training sessions rated as 5 or 6; $sRPE_{Hard}$ – internal load of training sessions rated as 7 or higher; HR Z1 – heart rate values below ventilatory threshold 1; HR Z2 – heart rate values between ventilatory threshold 1 and 2; HR Z3 – heart rate values above ventilatory threshold 2; * – The statistical associations ($P<0.05$) are shown in bold.

6. DISCUSSION

The aim of Paper I was to investigate the relationships between adolescent swimming performance and selected physiological parameters and sRPE-based internal training load in *Easy*, *Moderate* and *Hard* training sessions to quantify training load more appropriately. The main finding of Paper I was that internal training load accumulated in *Hard* training sessions was significantly related to changes in $\dot{V}O_{2max}$ and swimming performance with leg-kick only.

The purpose of Paper II was to investigate if the use of the same relative intensity and the same exercise duration result in different session perception in adolescent XC skiers and does this further have an influence on the adaptation aspect, as a secondary research question. The main finding of Paper II was that the same external load led to a significant variation in internal load and that subjects who accumulated higher internal load in low-intensity sessions had higher effects on improvement of maximal performance after a short, 1-week period.

The purpose of Paper III was to investigate the interaction of heart rate and RPE based training quantification methods and subjective parameters and their relationship to athlete's fatigue status during a 4-week high-volume load training period in members of the National Rowing Team. The main finding of Paper III was that the distribution of heart rate zones and effort-based zones were similar during the baseline week. However, the proportion of *Moderate* and *Hard* rated sessions significantly increased along with an increase in training volume and fatigue, while no changes were found in the respective proportions of the heart rate zones.

6.1. Relationships with sRPE based training load and performance (Paper I)

Training for endurance disciplines involves the manipulation of intensity, duration, and frequency of training sessions over days, weeks, and months. Previous studies (Esteve-Lanao et al., 2007; Seiler and Kjerland, 2006; Wallace et al., 2009) have suggested the distribution of training intensities into three intensity zones using physiological cut-off points for aerobic and anaerobic threshold. Categorization of RPE has also been used before in the literature (DeAndrade Nogueira et al., 2016; Seiler and Kjerland, 2006; Wallace et al., 2009). However, to the best of our knowledge, RPE based categorization of internal training load and its associations to changes in performance have not been studied before. Calculated per training session, the training plan of the subjects in Paper I included 63%, 20% and 17% sessions from *Easy*, *Moderate* and *Hard* sessions, respectively. A high number of *Hard* trainings could be expected, as the period of the study covered the last 10-weeks before the National Winter Championships. Accordingly, aerobic, and anaerobic threshold, as well as swimming performance, improved by 7.2%, 8.8% and 3.1%, respectively (Table 4). Total internal training load (sRPE) accumulated in the entire 10-week period was significantly related to the changes in anaerobic threshold (r=0.81). Anaerobic threshold can be considered as one of the variables that is most probably affected when internal training load is manipulated by using higher intensities. This is also indicated by the largest training effect on anaerobic threshold as the result of the training period (Table 4). Similarly, it was found that sRPE was related to both changes in aerobic and anaerobic threshold in 10-week low-intensity, high-volume period (Sanders et al., 2017). Somewhat similar results were also found in adolescent swimmers, where aerobic volume, defined by the swimming speed, was related to sRPE (DeAndrade Nogueira et al., 2016). However, aerobic volume in their study (DeAndrade Nogueira et al., 2016) also included swimming speeds that in comparison to those used in our study were higher than the anaerobic threshold. Wallace et al (2009) further suggested that the inclusion of interval trainings would increase the validity of sRPE as the measure of internal training load. Conclusively, this finding further indicates the use of sRPE as a global indicator of internal training load also in adolescent swimmers.

sRPE as internal training load indicator does not allow the coach to have feedback on whether the total load was accumulated by performing *Easy*, *Moderate* or *Hard* trainings. However, this would be useful knowledge because relating components of internal training load to positive adaptations and changes in performance is of high practical value (Hofmann and Tschakert, 2017; Mujika, 2017; Sanders et al., 2017). The important results of the Paper I were that those different measures of internal training load were related to changes in anaerobic threshold, $\dot{V}O_{2max}$ and swimming performance (r=0.76–0.81; $P<0.05$) in adolescent swimmers during the final preparation for competitions. Similar internal training load classification based on heart rate calculated TRIMPs has indicated that the categorization of training load can be used for analysing athletes' response to training and the resulting performance. Previous studies (Barroso et al., 2014; Wallace et al., 2009) have indicated that the validity of the RPE scale was related to the age, previous experience in using the scale, and the performance level of adolescent swimmers. For the purpose of overcoming these concerns at least partly, we aimed at validating the perception of the effort during the incremental test and applying the resulting RPE values as an additional reference for discriminating between *Easy*, *Moderate* or *Hard* training sessions, complementing the previously used categorization (Barroso et al., 2014; Seiler and Kjerland, 2006; Wallace et al., 2009). The application of sRPE.I method provided associations that were more precisely reflected in the compilation of the training plans where a great number of intensified sessions were used for enhancing performance. Using sRPE.I we found that the internal training load from *Hard* sessions was related to improvements in $\dot{V}O_{2max}$, and 100-m performance with leg-kick only. A tendency ($P<0.1$) towards 100-m freestyle performance improvement emerged (Table 5). These results generally support the findings of Sanders et al. (2017) who suggested that individualized concepts of internal training load could have higher validity and should be used to associate changes in fitness variables.

Despite individually manifested variations, internal training load accumulation indicated no significant differences between load distribution when using the sRPE.S and sRPE.I methods, while sRPE.W method indicated significantly less internal training load in the *Easy* training zone and significantly more load in higher zones (Figure 1). One explanation might be the use of the cut-off points by discriminating *Easy*, *Moderate* or *Hard* sessions. sRPE.S and sRPE.I are based on determining aerobic and anaerobic thresholds that have been shown to be a valid method in terms of the physiological response of the body after the training session relating to the RPE (Seiler and Kjerland, 2006). This is especially important in the case of high-intensity trainings that need higher effort rate than the anaerobic threshold. Due to lower cut-offs for both *Moderate* and *Hard* efforts for sRPE.W (see Table 3), a significantly higher amount of internal training load was accumulated in the moderate zone. The latter distribution also deviated from the initial training plan of the 10-week period, which included 37% of trainings categorized as *Moderate* or *Hard*. Furthermore, we found no associations between sRPE.W load measures and performance. Therefore, we suggest that the future studies should focus on sRPE.S and sRPE.I methods for internal training load categorization and relating to changes in performance in swimming as well as in other sports. The finding that sRPE.S and sRPE.I were related to different performance variables (anaerobic threshold and $\dot{V}O_{2max}$, swimming performance, respectively) could be explained by the 2-min incremental exercise protocol used for validating individual RPE cut-offs. Ideally, the threshold should appear as close as possible to verbal reporting of the RPE, which might be less accurate with 2-min step increments compared to 1-min increments. This might have influenced some of the trainings in the present study which were being categorized as *Moderate* instead of *Hard* effort. We, therefore, recommend that in future studies RPE should be asked after each min during the incremental test.

Internal training load categorization according to the effort could also have practical implications in terms of load-recovery interaction. Firstly, the recent study (Hofmann and Tschakert, 2017) argued that the specific exercise duration for any intensity plays a substantial role in the different kinds of fatigue and training effects. Furthermore, Maunder et al. (2021) indicated that the physiological responses of the body during prolonged exercise depend on the "durability" of the athlete, i.e. the time of onset and magnitude of deterioration in physiological-profiling characteristics overtime during the prolonged exercise. Categorization of internal training load could also be used accordingly. For example, performing aerobic threshold trainings at different duration should influence RPE (i.e., longer duration should have higher RPE). Therefore, in the future, it would be interesting to study how RPE responses at a certain intensity, especially during low-intensity sessions, can be used as targets for adaptations.

Secondly, a review article (Seiler, 2010) suggests an intensity distribution of 80% trainings in low-intensity and 20% in the high-intensity zone including threshold trainings. Furthermore, polarizing trainings and reducing the amount of moderate-intensity trainings may reduce sympathetic stress and the risk of overtraining (Seiler and Kjerland, 2006). In the current study, internal training load accumulated from *Hard* sessions was related to $\dot{V}O_{2max}$ and 100-m leg-kick only, which, however, does not mean that more *Hard* training sessions in practice will further increase performance, but as in the correct ratio of *Easy* or *Moderate* sessions. The categorization of internal training load can help coaches and athletes determine the proper balance between *Easy* and *Hard* training and thus, achieve better training adaptation. In our study, sRPE.S and sRPE.I methods indicated that approximately 25% of internal training load accumulated from *Hard* sessions and none of the athletes complained of excessive fatigue. However, the use of the interaction of RPE based internal training load categories for proper training adaptation should be further studied.

In conclusion, internal training load using the sRPE method was related to changes in performance in adolescent swimmers during the intensified period before the National Winter Championships. Using individualized sRPE values, the accumulation of the internal training load from *Hard* training sessions was significantly associated with changes in $\dot{V}O_{2max}$ and swimming performance. Therefore, we could recommend athletes monitor their internal training load using an individualized VT based sRPE quantifying method.

6.2. Different RPE during similarly prescribed sessions (Paper II)

Previous studies in XC skiers have shown a pattern of endurance training distribution with about 88–91% of low-intensity trainings (Sandbakk et al., 2011, 2016; Tønnessen et al., 2014). Similarly, the subjects' training plan during the study was mainly composed of low-intensity trainings, below VT1 (Seiler and Kjerland, 2006; Stöggl and Sperlich, 2015). Such a high amount of trainings at low-intensity suggest that we need to optimize duration and intensity interactions in order to plan low-intensity sessions for different purposes – to recover, stabilize or develop endurance capacity as a basic endurance performance (Hofmann and Tschakert, 2017).

If investigating low-intensity sessions, no significant differences were found for time spent in different heart rates zones ($P \geq 0.05$) between both groups (Table 7). Despite these trainings being planned as low-intensity sessions, a small amount of heart rate also accumulated in zone 3 (approximately 25 min for both groups), which was due to the uphill segments of the course. As for intensity, a given percentage of maximal aerobic intensity is widely used for training purposes, which is usually considered as the most important indicator of the endurance function (Bosquet et al., 2002). However, it has been demonstrated by Scharhag-Rosenberger et al. (2010) that there might be a huge variability of lactate responses among athletes at moderate to high aerobic work rates of 60 and 75% of $\dot{V}O_{2max}$. Numerous subjects were not able to maintain

75% of $\dot{V}O_{2max}$ for 60 min (Scharhag-Rosenberger et al., 2010), while others completed the task. Therefore, the degree of fatigue varies considerably between athletes who exercise at the same prescribed intensity. In our study, we applied individual thresholds well-known to represent the different training zones (Seiler and Kjerland, 2006) to overcome such a problem. However, despite having similar exercise prescriptions, subjects still rated their effort during low-intensity training sessions differently for all effort categories while no differences were found for time spent in different heart rate zones (Table 7; $P \geq 0.05$). On the other hand, Hofmann & Tschakert (2017) argued that manipulating exercise duration at a similar training intensity also results in different levels of fatigue provoking training adaptations. As of duration, Hofmann & Tschakert (2017) concept was modified from Platonov (1999) and from the critical speed concept (Pettitt, 2016), which suggests that coaches and athletes can target appropriate levels of fatigue and the resulting effort rating for optimal performance changes. Unfortunately, Hofmann & Tschakert's (2017) paper just gave a theoretical framework prescribing both intensity and duration for endurance training and no experimental proof has been shown yet. Maunder et al. (2021) also suggested that applied exercise physiologists working with endurance athletes would benefit from research to develop a valid physiological-profiling model that considers the effects of exercise intensity and duration on physiological load to account for individual athlete "durability" characteristics, which would allow more accurate training load monitoring. The results of our study support this hypothesis to some degree, indicating that RPE during and after training sessions, especially in the low-intensity domain could be one practical target to investigate in the future for different training duration effects at comparable intensities. For individual purposes, it is therefore obvious, that an extra parameter for the intensity-duration session planning needs to be implemented. Starting a low-intensity session with an RPE below the first turn point may lead to an increase in RPE and even exceed the rating to a level commonly seen in high-intensity sessions. Therefore, the low-intensity session turns *Hard* due to increasing fatigue which may induce different adaptation effects with the same low-intensity phenomenon prescribed by Viru (1992). In support of this, Seiler and Kjerland (2006) argued that session RPE may be useful in capturing elevations in exercise stress that are not because of acute intensity alone but reflected also by the duration of the session. In future studies, it should further be described whether similar target RPE values can be used in adolescent and adult athletes.

It is well known that performance development needs intense training, however, an individual and accurate intensity prescription is crucial even at low power outputs near VT1 since allowing intensities just 10% above VT1 may shorten the time to clear fatigue by ~40% (Hofmann and Tschakert, 2017). It is also indicated that a decrease in training power by 20 W in a single mountain bike athlete, allowed to increase total session time from 3 to 6 hrs and to accumulate significantly higher training volume without excessive fatigue (Hofmann, unpublished data). In Paper II we found a higher training load in G_{high}

(4010 ± 765 AU) compared to G_{low} (2499 ± 193 AU), respectively (P=0.034) during low-intensity trainings, while no differences were found in the high-intensity sessions between the groups. This could partly be explained by a slightly lower performance level in G_{high} which leads to a higher rating of training load within a similar heart rate zone. Despite the same target heart rates adapted for all the athletes, we found slight differences in changes of the $W_{max/kg}$ in ski ergometer performance observed after the training period. G_{high} showed a large increase (ES=0.67) in $W_{max/kg}$ (+12.5%), while statistically the increase was medium (ES=0.32) in G_{low} $W_{max/kg}$ (+10.7%). For future studies, we suggest that with a longer training period, performance differences would increase between the groups. As improvements in performance need appropriate manipulation with training load (frequency, intensity and duration) (Seiler and Kjerland, 2006), we argue that for G_{high} the duration of training and session rating (RPE) interaction was, at least for this short period, more favourable for performance changes compared to G_{low}. On the other hand, longer periods composed of several repeated loading cycles may overload athletes if targeted high-volume training shifts to moderate zone 2 intensity.

Subjective ratings from the questionnaires have been considered the most valid method for detecting too high or excessive training load (Halson, 2014). A within-subject test showed an increase in *fatigue* (P=0.035) and a decrease in *will to train* (P=0.011) in both groups. Such changes were expected, as the overall training load in the training camp was approximately 15–20% higher compared to the regular training load of these subjects. However, the average fatigue levels at day 7 (5.8 ± 2.4) on a 10-pt scale, further indicate that the training load during the camp was not excessive and did not have a significant impact on the second performance test. No differences in *fatigue* and *will to train* were observed between the groups (P≥0.05), which could suggest that the overall training status of the groups was not significantly different.

For an optimal adaptation to endurance training, the distribution of training intensities should also be considered. There is reasonably strong evidence to conclude that an approximate 80–20 ratio of low-intensity to high-intensity training is optimal for endurance athletes (Seiler, 2010). Low-intensity, longer duration exercises are necessary to stimulate adaptational responses (Tremblay et al., 2005), and high-intensity sessions should be performed (Stöggl and Sperlich, 2015) each initiating different adaptation. Therefore, we suggest that a certain amount of internal load at correctly targeted session rating is needed to accumulate at lower intensities below VT1 to gain optimal adaptation for this specific type of intensity-duration relationship. The same holds true for the higher intensities aiming at different adaptation targets. Interestingly, when looking at the internal load distribution for both groups in our study, G_{high} presented a distribution closer to the 80–20 concept and showed slightly higher performance improvement. If performance changes were corrected for internal load accumulated from intensive sessions the effect of training load on performance change increased (P=0.000; ES=1.94) in G_{high}, while it was not changed in G_{low}. These results indicate that the effects of performance change might be the result of training load distribution and for G_{high}, a higher effect on performance was obtained from training load from low-intensity sessions. Whether the use of longer sessions for the same intensity to obtain higher internal load from low-intensity sessions would have resulted in better performance in G_{low} needs to be addressed in further studies.

This study supports the concept that RPE might be a practical candidate marker to investigate the effects of the interaction between training duration and intensity on athletic performance. Despite training with a similar plan and with a similar external training load, young XC skiers reported training effort differently, which also resulted in small differences in performance changes between G_{high} and G_{low} after a 1-week training camp. The results indicate that the internal load of the sessions was different due to differences in endurance capacity, which is the maximal duration for this given intensity. Therefore, the same absolute exercise duration in minutes is a different percentage of maximal duration ability which is indicated by the earlier or later development of fatigue and differences in RPE and subsequent adaptation with a similar exercise prescription. The specific markers – RPE and critical speed may be potential markers that need to be investigated in more detail in further studies to improve individual prescription of exercise with the regard to both intensity and duration in the low-intensity domain.

6.3. Associations between fatigue and internal training load (Paper III)

The quantification of training sessions into different zones is a common practice in the endurance disciplines (Esteve-Lanao et al., 2007; Seiler and Kjerland, 2006) to optimise performance gains and to prevent overtraining. Mostly those quantifications have been based on heart rate usually applied to calculate training load, however, RPE-based quantifications have also been presented (Jesus et al., 2021; Seiler and Kjerland, 2006). If comparing the distributions of heart rate and effort-based zones, there were no significant differences in the baseline week (Figure 6). It has been shown that RPE is highly consistent with the heart rate measures (Foster et al., 2001). In addition to that, Seiler & Kjerland (2006) found no difference in intensity distribution between heart rate and RPE during a 32-days pre-competition preparation period in high-level XC skiers. They however distributed training bouts based on the RPE ratings, without calculating the respective internal loads ($sRPE_{Easy}$, $sRPE_{Mod}$, $sRPE_{Hard}$), thus the duration of each session was not considered. Recent studies indicate that it is not solely intensity, but also the duration of training sessions (Hofmann and Tschakert, 2017) that influence fatigue and therefore, could modify the post-training RPE response (Fusco et al., 2020a). Usually, differences in RPE are related to the intensity of the sessions only without including duration effects. In our study, most of the sessions were categorized as low-intensity, while a significantly higher intensity (lactate concentration about 6.0mmol/L) was used by Fusco et al. (2020a). In contrast, training approximately at 70% of $\dot{V}O_{2max}$ intensity with the manipulation of exercise duration between 20 to 40 min did not significantly influence RPE response (Green et al., 2009). Very recently, it was further indicated that at lower intensities (RPE response "*Easy*") the increase of session from 15 min to 30 min did not increase post-session RPE response, while a significant increase was found for "*Moderate*" and "*Strong*" intensities in recreational runners (Jesus et al., 2021). As the subjects in our study were high-level athletes with high endurance capacities, we can conclude that the similarities of heart rate and sRPE distribution during the baseline week with regular training volume could be expected due to the low intensities applied and the duration being short enough not to fatigue the subjects within a single session.

During the weeks of increased training volume (weeks 2 and 3) the proportion of the training sessions within the respective heart rate zones did not change, with approximately 20% of trainings performed at higher intensities than VT1. This is also consistent with what was found in the literature for endurance disciplines (Seiler and Kjerland, 2006; Seiler, 2010). Interestingly, there was a decrease in the number of *Easy* rated sessions and an increase in the *Moderate* rated sessions during weeks 2 and 3 that resulted in significant differences if compared to the respective heart rate zones (Figure 6). Moreover, there was a tendency ($P=0.06$) of a higher amount of $sRPE_{Hard}$ in week 4 compared to heart rate zone 3. Consequently, there was a shift in the RPE responses of the athletes indicating that sessions in general, became harder. At the same time, no changes in the respective heart rate indices were found. Firstly, this finding can be explained by the significant increases in session duration during weeks 3 and 4 that can cause higher acute fatigue, the concept that studies in the literature have also indicated (Barroso et al., 2015; Fusco et al., 2020a; Jesus et al., 2021). Jesus et al. (2021) found that using the intensities relative to RPE value 3, already caused increases in RPE if exercise duration increased from 15 to 30 min. As the subjects in our study were high-level rowers with high-performance capacities, the *Easy* session represented the RPE values ≤4 that correspond to intensities up to the aerobic threshold (Seiler and Kjerland, 2006). Therefore, significant increases in session volume, despite being on the average 10 min longer for weeks 3 and 4 compared to week 1, might contribute to some changes in post-exercise RPE for our subjects. Secondly, during such high-volume periods, training stress might increase recovery demand which disturbs the balance between training and recovery resulting in a non-functional overreaching (Meeusen et al., 2013). Accordingly, we found significant increases in several stress scales because of increased training volume and interestingly, some of them (*Social Stress*, *Conflicts/Pressure*, *Fatigue*, *Physical Complaints*, *Disturbed Breaks*) even increased ($P<0.05$) during the recovery week. The increased scores for *Fatigue* in week 3 can be expected after a significant training volume increase in week 2 compared to the baseline week (Figure 5). However, the significant increase in *Fatigue* after the recovery week (week 4) was somewhat unexpected. The reason for that is difficult to explain, but most likely the overall training load during week 4 was still too high that did not allow the dominance of recovery processes. We also cannot rule out the training intensity distribution effect on fatigue accumulation as Guellich et al. (2009) reported a 95–5% zone distribution of total rowing time performed either at lower or higher intensities compared to VT1. Therefore, we suggest that the overall athletic status by the end of week 4 was still compromised (González-Boto et al., 2008; Halson, 2014; Jürimäe et al., 2002) that were also reflected by higher RPE responses. Similarly, it has been indicated that accumulation of fatigue can influence RPE response after sequential days of relatively hard mixed-intensity sessions (Fusco et al., 2020b). Increased RPE scores have been found in the last stages of short (5–7 days) and in long (2–3 weeks) 21-day cycling race, resulting in an increase of the slope of the relationship between heart rate and TRIMP scores (Rodríguez-Marroyo et al., 2012). These studies and our current results clearly indicate that RPE might be a more sensitive parameter to calculate internal training load compared to methods based on heart rate time-in-zone calculations, especially during fatigue accumulation to prevent overtraining (Rietjens et al., 2005).

To the best of our knowledge, Paper III is the first to investigate RPE based training quantification during a volume increased, mainly low-intensity training cycle and how this quantification might reflect the fatigue status. Recent studies showing the possible effect of fatigue on post-exercise RPE have rather used higher intensities (>VT2) (Fusco et al., 2020a), mixed intensities (Fusco et al., 2020b), being very short on session volume (Green et al., 2009; Jesus et al., 2021), or have used cycling tours (Rodríguez-Marroyo et al., 2012; Sanders et al., 2018). Our study focuses on a common preparatory period mesocycle where low-intensity trainings below VT1 are dominant. Additionally, an important finding of the study was that *Fatigue* scale was related to the amount of RPE-based *Moderate* ($sRPE_{Mod}$) and *Hard* ($sRPE_{Hard}$) effort sessions (P=0.011 and P=0.008, respectively; Table 9), while no effects were found for heart rate-based session quantifications. Those findings indicate that quantification of training load by effort-based zones might have a further advantage compared to single load (sRPE or TRIMP) quantification. A similar hypothesis was prescribed by Hofmann & Tschakert (2017), who pointed out that manipulating exercise duration at a similar training intensity results in different levels of fatigue and therefore, the stress level of athletes. Therefore, training prescribed at heart rate <VT1 for example, may be quantified by 3 or 6, based on different session duration or the fatigue status of the athlete, which in practice might change the training session effect significantly (Hofmann and Tschakert, 2017).

It has been proposed that different trainings at higher intensities than VT1 should be well balanced for moderate and high-intensities and should not exceed 20% of overall training volume to avoid excessive sympathetic stress (Seiler, 2010). The same might apply for RPE based quantification such as a certain amount of high load can be tolerated by athletes to induce positive adaptations. This high load can either be the result of *Hard* and short high-intensity session or *Hard* rated low-intensity session if performed for a sufficiently long duration. It should also be indicated that total sRPE load (AU) during the 4-weeks was negatively associated with fatigue accumulation. This surprising finding is probably the result of the increase in *Fatigue* level despite a significant decrease in training load at week 4. Future studies are clearly warranted to study the applicability of effort-based session quantification in the use of different training periods. Based on the current results, our study extends the knowledge in the literature, that during low-intensity, high-volume training cycles a state of increased fatigue can be determined better by RPE rather than heart rate-based methods to determine the excessive development of exercise-related stress. However, it should be the aim for future studies to target different training periods, different disciplines and for potential changes in performance.

6.4. Limitations of the dissertation

The current dissertation has some limitations that should be considered. Firstly, in Paper I, the sample size was relatively small for distinctive conclusions to be drawn. Previous research (Barroso et al., 2014) has indicated that RPE reports in adolescent swimmers might have relatively large variation for the same session. However, this was not the case in our Paper I, probably because of the previous experience of subjects with the RPE scale during the training process. Nevertheless, the lower number of associations could be explained by the combination of some variation in RPE responses and a relatively low number of participants. Previous studies have indicated different responses of effort to similar training sessions between boys and girls (DeAndrade Nogueira et al., 2016). However, we also adjusted our results in Paper I to the sex of the subjects (data not shown), and this revealed no significant effect on the overall results. In contrast, the research data have strong ecological applicability, being collected from highly trained adolescent swimmers during the final preparation to competitions and in the real training environment. The use of the 2-min duration loads when asking RPE during the incremental test should be considered as a limitation if validating RPE against VT1 and VT2. Unfortunately, we were not able to change the 2 min protocol since this has been the routine test for the subjects.

In Paper II, the maturation status of the subjects was not investigated, which could have had a different impact on performance. However, as the groups were formed using RPE during the training period, the subjects with different maturation statuses are likely to be distributed randomly between groups, as was with the age that remained similar in both groups (Table 6) and therefore, could lower its actual effect on performance in group comparison. Secondly, there was an inequality (because of the small sample size) between girls and boys distributed between the groups. G_{low} had 1 girl and 5 boys, while G_{high} had 3 girls and 4 boys. However, it did not play a dominant role for the main research question – whether similar external load could incuse differences in internal load reported as sRPE. We should also consider the length of the training intervention, which was relatively short and therefore, a longer period covering several micro-cycles and at least 1 to 3 macro-cycles (4–12 weeks) should be studied. Despite that, the effects of single sessions and defined periods should be studied to understand the overall training effects. Therefore, slightly different effects on performance presented in the current study between the groups might be influenced by those factors. As well, Paper II was not a prospective experimental study, as we did not manipulate to attain a certain RPE during the training session. The study was retrospective to test the hypothesis of the use of RPE in low-intensity trainings as a potential marker for adaptation. We found that effort rating is different, despite individually prescribed session intensity, and overall similar duration.

Paper III was also not a prospective experimental study to directly compare the effects of different session quantification methods related to either increase in training volume or fatigue. Secondly, as it was not a laboratory-controlled study, different factors like hydration status or glycogen depletion (Snyder, 1998), or different heart rate – RPE method interaction depending on the exercise type (Lupo et al., 2016) might affect heart rate or RPE response to a different extent and needs to be considered. The diet of the subjects was not controlled, however as the subjects of the study were national team members or candidates, they have had counselling on proper nutrition. Also, the relatively short period of data collection (4-weeks) may be considered as a limitation of the study. On the other hand, this period stands for a full mesocycle and was conducted under real field conditions having a sample of well-trained athletes. For future studies, an additional type of mesocycles needs to be investigated applying the same proven and useful concept. Finally, we did not study training effects on performance during the 4-week period. We have recently found that different post-exercise RPE values could modify training effects (Paper II), therefore targeting for certain RPE, based on session aim could give further information on the effect of the session on the adaptation of athletes.

7. CONCLUSIONS

Based on the results of the current dissertation, the following conclusions were made:

1. Internal training load using the sRPE method accumulated in *Hard* training sessions was significantly related to improvements in $\dot{V}O_{2max}$ and swimming performance in adolescent swimmers (Paper I).
2. Training with a similar external training load, with matched training volume and intensity, resulted in a significant variation in internal load (sRPE) in young XC skiers indicating different strain from similarly prescribed trainings (Paper II).
3. Subjects who accumulated higher internal load in low-intensity sessions had higher effects on improvement of maximal performance after a 1-week training period (Paper II).
4. During a volume increased low-intensity training cycle in rowers, RPE based training quantification indicated a shift towards harder rated sessions compared to unchanged heart rate quantification (Paper III).
5. RPE based *Moderate* ($sRPE_{Mod}$) and *Hard* ($sRPE_{Hard}$) sessions were related to increase in the RESTQ-Sport *Fatigue* scale, supporting the use of the polarized training model concept, where the critical anchor point for endurance training planning is aerobic threshold (Paper III).

8. PRACTICAL APPLICATIONS

8.1. The benefits of internal load categorization for monitoring the training process (Paper I)

A better understanding of the association of the internal training load with changes in performance is valuable for coaches working in practice. In Paper I we analysed internal load from different training efforts as *Easy*, *Moderate* and *Hard*, based on the RPE categorization previously used in the literature (Barroso et al., 2014; Seiler and Kjerland, 2006; Wallace et al., 2009) in relation to changes in performance during the final preparation of National Swimming Championships in adolescent swimmers. As we found relationships between training load categories and changes in performance, this categorization could help coaches to estimate and quantify load to evaluate the training process and the resulting adaptation of the athlete more precisely. It should be considered that the effort can turn hard at low or moderate intensities if the training gets too long. Furthermore, relating internal load from *Hard* sessions to *Easy* sessions could help to monitor the training process for targeted adaptation.

8.2. A certain RPE-level as a target for low-intensity training sessions (Paper II)

Adaptation to endurance training needs proper manipulation of training duration and intensity during a single session. High-intensity (interval) sessions are targeted to induce performance improvement using (near) maximal efforts and those sessions are relatively easy to plan. However, in low-intensity sessions the overall effort of the acute training might be different, ranging from recovery to base training or capacity building effects as well as improvements in the economy, depending on the session duration and overall intensity. Our findings suggest that at lower intensities targeted for individual heart rates, RPE might be different and therefore, could induce different adaptation effects. We propose that for improvement of performance the overall effort (RPE), even for low-intensity training sessions needs to be targeted to a certain RPE level which, however, is a subject of future studies. There is some preliminary experimental support for the different duration effects showing that even enhanced recovery can be provoked by stopping sessions as early as 20% of the maximal duration (Weiner et al., 2019). With such an approach, coaches may prescribe optimal session duration-intensity interactions aiming at specific training targets even for the low-intensity training sessions.

8.3. Progressive fatigue and usefulness of RPE based training load (Paper III)

The precise quantification of training load for every individual could contribute to a more accurate assessment of how the athlete is responding to the prescribed training session or training cycle. To have an impact on performance we must be sure of the nature of the relationship between the prescribed exercise dose and the expected training outcome or response. The heart rate-based time-in-zone approach is a rather easy method to measure training load, however, the heart rate might drift to lower or higher values over the course of a longer workout or training cycle. We found that RPE drifted towards harder rated sessions compared to unchanged heart rate quantification during a volume increased, low-intensity training cycle. It was supported by the increase of the *Fatigue* scale of the RESTQ-Sport questionnaire. Furthermore, *Moderate* and *Hard* sessions were associated with increased *Fatigue*, while it was not the case with *Easy* sessions. Therefore, we could suggest that during the volume intended training periods, the overall session perception should be targeted as *Easy* (PRE $\leq$ 4) to tolerate high training volumes.

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SUMMARY IN ESTONIAN

Sisemise treeningkoormuse kvantifitseerimine ja selle praktiline rakendamine treeningul

Treeningu intensiivsus, kestus ja sagedus on kolm olulist ja peamist komponenti, millega manipuleerides saab sportlase sooritusvõimes esile kutsuda kohanemisprotsesse, mis on olulised kõrgete sportlike tulemuste saavutamiseks. Need kolm komponenti kombineerituna piisava puhkusega tagavad organismis adaptiivsed muutused, mille tulemusena eelduslikult paraneb sportlase sooritusvõime. Keeruliseks muudab aga treeningute planeerimisel täpse ajahetke määramine, mil positiivse mõjuga treeningud võivad muutuda sportlase jaoks negatiivseteks, sest treeningukoormus osutub liiga suureks. Samas on aga ka võimalik, et koormused on liiga madalad kutsumaks esile positiivseid kohanemisreaktsioone. Seetõttu on üheks treeningute planeerimise oluliseks osaks treeningkoormuse mõõtmine ja jälgimine.

Treeningkoormust on sportliku treeningu kontekstis kirjeldatud kui ärritajat või stressorit, et sellega kohanedes organismis soovitud reaktsiooni esile kutsuda (Coutts et al., 2017). Treeningkoormust saab kirjeldada kahe erineva suuna alusel – väline ja sisemine treeningkoormus. Enamasti kirjeldatakse treeningkoormust välise suuna abil, milleks on näiteks treeningu kestus, läbitud vahemaa või tõstetud raskused. Küll aga sõltub tegelik sportliku sooritusvõime muutus indiviidi adaptatsioonist välisele treeningkoormusele, mistõttu on oluline jälgida ka sportlase füsioloogilist reaktsiooni ehk sisemist treeningkoormust (Halson, 2014). Sisemise treeningkoormuse hindamiseks on enam levinumad markerid näiteks südame löögisagedus, vereplasma laktaadi kontsentratsioon, hapniku tarbimine. Kõik nimetatud parameetrid nõuavad aga spetsiaalset aparatuuri ning mitte kõik nendest pole praktikas lihtsasti kasutatavad (Barroso et al., 2014; Impellizzeri et al., 2004), on aeganõudvad või kallid. Kõige levinumaks meetodiks treeningul sisemist koormust hinnata on südame löögisageduse määramine. Samas on teada, et südame löögisagedus on mõjutatud erinevate väliste faktorite poolt ning see ei ole alati usaldusväärne intensiivsete intervalltreeningute, vahelduva intensiivsusega treeningute, jõusaali treeningute või plüomeetriliste treeningute puhul (Barroso et al., 2014). Südame löögisagedus võib olla lisaks veel ka tundlik pikkade treeningute puhul (Gilman, 1996; Lucia et al., 1999) näiteks sportlase väsimuse kuhjudes kõrgemahulise treeningperioodi jooksul.

Üheks praktiliseks meetodiks, lisaks eelpool nimetatud objektiivsetele mõõtmistele, on kasutada sportlase hinnangut treeningukoormusele. Subjektiivne treeningu raskusaste 10-punktisel skaalal (RPE) peegeldab indiviidi subjektiivset reaktsiooni treeningu intensiivsusele ja kestusele (Foster, 1998; Foster et al., 2001) ning korrutades RPE treeningu kestusega saame hinnangu sportlase sisemisele treeningukoormusele (sRPE) (Foster et al., 2001). Antud meetodit on kasutatud erinevate vastupidavuslike spordialade puhul (Foster et al., 2001; Roos et al., 2018; Sanders et al., 2018; Seiler and Kjerland, 2006;

Tran et al., 2015; Wallace et al., 2009, 2014), aga ka erinevate pallimängude ja jõutreeningute puhul (Foster et al., 2021).

Vastavalt treeningu ning treeningtsükli iseloomule saab sRPE meetodit suhteliselt lihtsasti kasutada, et seeläbi sportlase väsimusastet vastavalt vajadusele kas suurendada või vähendada (Meeusen et al., 2013). Vastupidavusaladel on tavapärane kategoriseerida treeningute intensiivsust erinevatesse treeningtsoonidesse, millest enim levinud on niinimetatud „kolme tsooni mudel" (Seiler and Kjerland, 2006). Lucia et al. (2003) meetodi kohaselt saab treeninguid jagada kolme intensiivsustsooni vastavalt ventilatsiooni lävedele, mis on määratud astmelisel koormustestil. Sarnaselt võiks kasutada ka treeningu sisemise koormuse kategoriseerimist. Seiler & Kjerland (2006) viitasid, et treeningu järgsel RPE väärtusel esineb seos, millises intensiivsustsoonis treening sooritati. Järelikult on võimalik ka treeningukoormust vastavalt kategoriseerida, mille tulemusel saab subjektiivse hinnangu alusel määrata kerged ja rasked treeningud, kasutades näiteks 10-punktilise skaala hinnanguid koormustestidelt, sidudes vastavad RPE hinnangud aeroobse või anaeroobse läve intensiivsusega või kasutades kerge, keskmise või raske treeningu määramisel Seileri & Kjerlandi (2006) poolt välja toodud fikseeritud RPE väärtuseid. Selline lähenemine võib olla sportlastele ja treeneritele abiks, et treeningute monitoorimise protsessis ka treeningute koormust paremini hinnata. Seega saame väita, et sisemise treeningkoormuse kategoriseerimine on vajalik sportliku sooritusvõime kontekstis.

Käesoleva doktoritöö põhieesmärk oli uurida sisemise ja välise treeningkoormuse kategoriseerimise meetodeid erineva kestusega treeningtsüklite ajal ning uurida nende seoseid sooritusvõime ja väsimusega. Vastavalt doktoritöö põhieesmärgile seati järgmised konkreetsemad eesmärgid:

1. Uurida seost sisemise treeningkoormuse kategoriseerimise ning ujumise sooritusvõime vahel noortel ujujatel (Uuring 1).
2. Analüüsida, kas tajutav pingutuse raskusaste (RPE) ja sellest tulenev sisemine treeningkoormus (sRPE) erinevad noortel murdmaasuusatajatel, kui treeningmaht ja intensiivsus on ühtlustatud (Uuring II).
3. Analüüsida, kas kõrge või madala RPE hinnangu ja vastava sisemise koormuse näitajatega suusatajad kohanevad treeninguga erinevalt pärast 1-nädalast madala intensiivsusega kõrgemahulist treeningperioodi (Uuring II)
4. Uurida interaktsiooni treeningkoormuse kategoriseerimisel kahe erineva meetodi vahel: südame löögisagedus ja subjektiivne hinnang (RPE). Lisaks uurida seost sisemise treeningkoormuse parameetrite ja subjektiivse väsimuse vahel kõrgetasemelistel sõudjatel madala intensiivsusega kõrgemahulisel treeningperioodil (Uuring III).

Käesolev doktoritöö koosneb kolmest eraldiseisvast uuringust. Uuring I puhul kasutati 8 rahvuslikul tasemel ujujate andmeid. Uuringuperioodi kestus oli 10-nädalat. Uuringus II osales 13 rahvuslikul tasemel murdmaasuusatajat. Uuringuperiood oli kestusega 1-nädal eesmärgiga suurendada treeningmahtu ~20% võrreldes möödunud nädalatega. Uuringu III andmeanalüüsi kaasati 19 kõrgetasemelist sõudjat, kes võtsid osa 4-nädalasest kõrgemahulisest treeninglaagrist.

Käesoleva doktoritöö tulemuste põhjal tehti järgmised järeldused:

1. sRPE meetodiga rasketest treeningutest tekkinud sisemine treeningkoormus oli seoses maksimaalse hapniku tarbimisvõime ($\dot{V}O_{2max}$) ja ujumise sooritusvõime paranemisega noortel ujujatel (Uuring I).
2. Sarnase välise koormusega treeningud, kus treeningute kestus ja intensiivsus olid ühtlustatud, leiti erinevused sisemise treeningukoormuse väärtustes noortel murdmaasuusatajatel (Uuring II).
3. Uuritavad, kel madala intensiivsusega treeningute tagajärjel akumuleerunud sisemine treeningukoormus oli kõrgem, parandasid töövõimet suuremas ulatuses pärast 1-nädalast treeningperioodi võrreldes uuritavatega, kelle sisemine treeningkoormus oli madalam (Uuring II).
4. Suuremahulise madala intensiivsusega treeningtsükli ajal toimusid olulised muutused RPE-põhise treeningkoormuse kategoriseerimise meetodi tunnuste vahel. Samas ei tuvastatud muutusi treeningute kategoriseerimises intensiivsustsoonidesse südame löögisagedusel põhinevat meetodit kasutades (Uuring III).
5. RPE hinnangul põhinev keskmise ja raske treeningu akumuleeritud koormus oli usutavas seoses RESTQ-Sport küsimustiku alaskaala *Väsimuse* muutusega (Uuring III).

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Sports performance, physical performance, economy and technique of endurance disciplines, training monitoring

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Peamised uurimisvaldkonnad:
Sportlik sooritus, kehaline töövõime, vastupidavusalade ökonoomsus ja tehnika, treeningute monitooring

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