The relationships between training load and stress and recovery with performance, injury rate and training adherence in well-trained female collegiate UK rowers

Anerida Coetzee

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Supervised by: Dr Sarah Davey
Director of studies: Dr John Jakeman

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II. Abstract

Quantifying training is important when evaluating athletes' responses to training intensity distribution and training load. Monitoring training load, training intensity distribution and the balance between stress and recovery can be used to optimise supercompensation, prevent overtraining, injury and inform coaches on the "readiness" of athletes to perform certain training. The main aim of this study was to investigate whether the Acute Recovery and Stress Scale (ARSS) can be used to monitor acute training load in well-trained female-student rowers.

Twelve female rowers (mean ± SD, age: 20.1 ± 0.9 years; height: 178.25 ± 7.88 cm; weight: 78.43 ± 7.27 kg; body fat: 21.83 ± 3.78 %; training sessions: 11 ± 3 sessions·wk^{-1}; training duration: 9.1 ± 2.4 hrs·decimin) were monitored over a 15-week training period. Daily training load assessed by both objective and subjective measures of exercise intensity i.e. heart rate (HR_{TL}) and sessions rating of perceived exertion ($sRPE_{TL}$), respectively, were recorded in addition to volume load for resistance training, training intensity distribution below (<LT1) and above (>LT1) lactate threshold, and adherence to training. On a weekly basis, stress and recovery was assessed by the ARSS Questionnaire (Nässi *et al.*, 2017) and power output was assessed by a 30-min bout (PO_{30}) of rowing. Pre- and post-study athlete burnout was assessed using the Athlete Burnout Questionnaire (ABQ Raedeke and Smith, 2001).

Pearson correlations indicated significant moderate relationships between training distance and $sRPE_{TL}$ (r = 0.656, p = 0.032, 95 %CI: 0.129 – 0.952) and HR_{TL} (r = 0.591, p = 0.043, 95 %CI: 0.084 – 0.908); HR_{TL} and mean difference in PO_{30} (r = 0.606, p = 0.037, 95 %CI: 0.174 – 0.863); and a significant strong relationship between $sRPE_{TL}$ and *Physical Performance Capacity* (ARSS construct) (r = 0.784, p = 0.004, 95 %CI: 0.378 – 0.967). No other significant relationships were determined between the ARSS constructs and training load measures. Paired T-tests determined that there was no significant difference (p > 0.05) for ABQ constructs.

Therefore, on a group level in this population, training load can be monitored using HR_{TL} but not $sRPE_{TL}$ or the ARSS. Due to the moderate relationship's other parameters (e.g. blood lactate, creatine kinase, biomarkers, etc.) may need to be included to provide an accurate reflection of training load. Results need to be investigated on an individual level to determine whether ARSS can track the acute responses to training load within

individuals. In addition, it is possible that ARSS may be more effective when used to measure chronic training load.

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HR – heart rate

HR_{TL} – heart rate TRIMP method used in the current study

LT1 – lactate threshold 1/ aerobic threshold

LT2 – lactate threshold 2/ anaerobic threshold

PO – power output

PO_{30} – power output for 30-minute performance

PO_{2km} – power output for 2 km performance

RPE – rating of perceived exertion

sRPE – session RPE

$sRPE_{TL}$ – session RPE training load

TRIMP – training impulse

1. Introduction

Rowing is a physically demanding strength-endurance sport with elite rowers being reported to have training loads of up to 20 $h{\cdot}wk^{-1}$ including distances rowed of up to 140 $km{\cdot}wk^{-1}$ (Tran *et al.*, 2015b). Competitive 2 km rowing is both an anaerobic and an aerobic sport using between 20-25 % and 75-80 % of the respective metabolic energy systems during a 2 km rowing event (Nolte, 2011). For success in races rowers are required to train at intensities that place both the anaerobic and aerobic metabolic energy systems under stress i.e. below, at or over both an individual's aerobic and anaerobic metabolic thresholds. To place the metabolic energy systems under stress the athletes are required to train at and/or above their individual thresholds to develop the capacity and improve the ability of athletes to sustain high power outputs during a race by eliciting desired adaptations (e.g. aerobic threshold training elicits increases in: maximal cardiac output, maximal ventilatory capacity, aerobic enzyme activity; see section 3.7.1.1 Table 3.2). To meet this requirement, recent evidence has suggested that a polarised training programme is conducive for athletic development and performance in endurance sports (Stöggl and Sperlich, 2014). Polarised training has been defined as majority (~80 %) of the training conducted at an intensity below aerobic threshold (<LT1) and the remaining volume (~20 %) of training being conducted above aerobic threshold (>LT1) (Seiler and Kjerland, 2006). By quantifying the training practices of elite and national class rowers, Stöggl and Sperlich (2015) found in their review that rowers in this population tend to adopt this polarised approach with 75-96 % of training being conducted under LT1. Hartmann *et al.* (1990; cited in Stöggl and Sperlich, 2015), also observed that the polarised approach changes during the season for rowers from preparation (86-94 % below LT1) to competition phase (70-77 % below LT1), a similar approach to that observed by Tran *et al.* (2015b) also in rowers, suggesting that the training intensity distribution is also periodised to suit the needs of the athlete in that phase.

Individual rowers may require differing optimal quantities of polarisation (e.g. 95:5, 75:25, 86:14; Stöggl and Sperlich, 2015) and training loads based on their competitive level, training background and anatomy and physiology (Seiler *et al.*, 2007) due to individuals responding differently to a training stimulus by gaining the required adaptions or not responding correctly (i.e. under-stimulated, or overstimulated) (Halson, 2014). Understanding these individualised training loads are important for rowers' athletic development, performance and preventing of overtraining, injuries and burnout (Kellmann *et al.*, 2018).

Training loads can be divided into external and internal loads. External training loads are the external training stressors placed on the athlete such as distance, duration and power output and internal training loads are the physiological and/or psychological responses that the athlete experiences to the external training stressors (e.g. heart rate, lactate production, muscle damage, oxygen consumption). Banister (1991) developed a method named 'training impulses' (TRIMPs) to quantify internal training load. To quantify internal training load Banister's 1991method uses heart rate reserve (heart rate during exercise minus heart rate at rest) to quantify the intensity of exercise, with a weighting factor based on gender and other non-gender specific values and duration of exercise (Banister, 1991). Subsequent TRIMP models have slightly differed either by introducing more weightings to the heart rate measurements to reflect different training zones athletes may utilise e.g. Edward's TRIMP 5-zone heart rate intensity model (Edward, 1993) or the Lucia et al (2003) 3-zone model that is devised on heart rates values associated with ventilatory thresholds or have utilised subjective ratings such as session rating of perceived exertion (i.e. sRPE; Foster *et al.*, 2001).

The T2minute method (Tran *et al.*, 2014) was developed specifically for rowing by including exercise mode-specific weighting factors that are weighted according to how intense the mode is compared to on-water rowing. Unlike with Edwards TRIMP (i.e. 5-zone intensity model), the T2minute method uses a 10-zone intensity model based on lactate thresholds which are determined every 12-weeks with an incremental step test. The method does not require heart rate to be measured as the calculation only requires duration of exercise, training zone desired and the mode of exercise. Therefore, it is a useful method to utilise when measures of HR cannot be obtained, but its accuracy is highly dependent on the training prescribed being appropriate to achieve the training zones desired.

Another important element to consider is the balance between stress (i.e. internal training demands; and other external stressors such as personal life and academic demands) and recovery (i.e. rest and relaxation internally – sleep and rest; and externally – socially). Recovery is a key aspect of supercompensation (i.e. increase in performance above the baseline load level after an increase in training stress levels with a sufficient amount of recovery) caused by training load and may hinder the performance if not adequate (Seiler *et al.*, 2007). The result of a sufficient balance between recovery and stress will likely lead to improved performance (Pelka and Kellmann, 2017), where an imbalance over an extended period of time may lead to overreaching and injury or attenuate potential development (Foster, 1998). As a consequence, it is important for a coach and athlete to attain the optimal balance between stress and recovery within the different training cycles of a periodised season (i.e. general preparation; specific preparation; pre-competition; competition; and transit) to allow the rower to optimally develop and to perform successfully by peaking when needed.

Stress and recovery have been assessed using questionnaires such as: Acute Recovery and Stress Scale (ARSS) (Kölling *et al.*, 2015), Short Recovery and Stress Scale (SRSS) (Kellmann and Kölling, 2019), and Recovery and Stress Questionnaire for Athletes (RESTQ-Sport) (Kellmann and Kallus, 2001). The questionnaires focus on both the physical and cognitive stress that athletes incur in response to training and personal life stressors. Relationships between recovery-stress scales and training loads have been determined in rowers (ARSS - Kellmann and Kölling, 2019; RESTQ-76 - Mäestu *et al.*, 2006) and swimmers (ARSS - Collette *et al.*, 2018). In Mäestu *et al.* (2006), the RESTQ-Sport was validated on 12 male national rowers over a 6-week preparation phase period. The first week was a reference week, where after the volume was adjusted to increase or decrease the stress on the rowers on a weekly basis. The RESTQ-Sport was completed once a week after a rest day and was compared to creatine kinase and cortisol that was collected on the same day. It was determined that creatine kinase activity was significantly related to Standardised recovery scores ($r = -0.45$; $p < 0.008$; $n = 72$), followed the training volumes by increasing in the high training period and decreasing in the low training period. Therefore, concluding that the RESTQ-Sport is able to track changes in training. Whereas, in Collette *et al.* (2018) 5 female high-performance swimmers were monitored over a 17-week period for daily recovery-stress scores using the ARSS questionnaire. The questionnaire was implemented every morning before training and was compared to different $sRPE_{TL}$ training load measures where relationships were determined with the physical and overall-related constructs of the ARSS (i.e. mean cross-correlation [MCCC][range]: *Physical Performance Capacity* with $sRPE^{km}$ = -0.27 [-0.21/-0.35]*; Overall Recovery* with $sRPE^{km}$ = -0.36 [-0.23/-0.50]*; Muscle Stress* with $sRPE^{km}$ = 0.52 [0.66/0.37] and with $sRPE^{h}$ = 0.41 [0.48/0.33]*; Overall Stress* with $sRPE^{km}$ = 0.39 [0.46/0.21]). Within both of these studies the athletes were at a high-performance or national level and were not dual career student-athletes, and to the authors knowledge relationships between recovery-stress scales and training have not yet been assessed in well-trained UK female student rowers; a population where there is a prevalence of burnout (Dubuc-Charbonneau *et al*., 2014).

Unlike the majority of elite athletes, student-athletes can be considered as athletes undergoing dual-careers (i.e. pursuing both sporting and academic careers simultaneously). Therefore, in addition to sporting-related stressors, student athletes can also experience other various academic and social stressors. They also face the constant challenge of performing in both sporting and academic contexts (Hamlin *et al.*, 2019). As a consequence, levels of burnout in student-athletes have been examined with the establishment that female student-athletes generally experience higher levels of burnout than male student-athletes (Dubuc-Charbonneau *et al*., 2014). It is therefore important in this population for coaches and athletes to prescribe and monitor training stress (i.e. training load) and recovery to ensure the balance is appropriate for athletic development and subsequent performance and to prevent an imbalance that could lead to burnout. Resources for student-athletes and their support team are usually less than their elite and sub-elite counterparts. As a consequence, due to the time and cost of monitoring training loads and recovery using methods such as HR and RPE based TRIMPs and heart rate variability, monitoring internal training loads and recovery may not often occur in this population. If strong relationships also exist between training load and recovery-stress questionnaires in this population there is the potential for the questionnaires to be used as an indirect measure of training load as opposed to more expensive and time consuming methods aforementioned; thus possibly increasing the prevalence of training stress and recovery being monitored in this population.

To the authors' knowledge there are no publications that have examined relationships between subjective measures of recovery-stress questionnaires and training load measures in UK based female student-athlete rowers and how they relate to subsequent performance and adherence. In addition, there is limited information of the training practices in this population. Therefore, the aims of this investigation are to: i) describe the training practices of UK female student rowers; ii) determine the relationships between different measures of internal load and external training load;; iii) determine the relationships between different measures of internal training load and responses to recovery-stress questionnaires; and iv) determine the relationships between training load and rowing performance.

2. Literature Review

2.1. Physical determinants of rowing performance

2.1.1. Characteristics of 2 km rowing

Rowing is a very physically demanding strength-endurance sport with elite rowers being reported to have training loads of up to 20 $h \cdot wk^{-1}$ including distance rowed of up to 140 $km \cdot wk^{-1}$ (Tran *et al.*, 2015b). Typical races consist of a distance of 2 km that lasts between 5–8 minutes and can be raced in a single scull, double scull (coxed and coxless), quadruple scull (coxed and coxless), and a coxed eight boat. Competitive 2 km rowing utilises both aerobic and anaerobic metabolic systems using between 75-80 % and 20-25 % of the systems, respectively (Eberle, 2014). During the 2 km race female rowers utilise approximately 96% of their VO_{2max} and 98% of their HR_{max} with blood lactate concentrations reaching 11.8 ± 5.2 $mmol \cdot L^{-1}$ (Perkins and Pivarnik, 2003). Training programmes are typically periodised into different phases, e.g. preparation to competition, focusing on both strength and endurance on both water and land (Steinacker, 1993). Programmes include complementary sessions such as strength and conditioning; running; and cycling (Mikulic, 2011; Steinacker *et al.,* 1998; Tran *et al.*, 2015).

2.1.2. Physiological determinants

A range of physiological parameters influence rowing performance and a number of investigations use 2 km time trial performance on a rowing ergometer as a proxy for on-water performance. Even though it has been established that rowing on the rowing ergometer and on water are different in technique (Mäestu *et al.*, 2005), the validity of this method is supported by the results of Mikulić *et al.* (2009) who observed relationships between 2 km performance on the water and ergometers in junior rowers. Within the range of r = 0.64 – 0.92 ($p \leq 0.025$) for smaller boats (i.e. singles and doubles) and between r = 0.31 – 0.70 ($p \leq 0.039$) for larger boats (i.e. quads and eights). The variance of the correlation results differs from small to very strong this reduces the confidence that the 2 km ergometer can predict 2 km on-water, especially in larger boats where the confidence interval ranges from very small to moderate. McNeely (2012) conducted a study to determine whether 2 km ergometer rowing and 2 km on-water had a relationship and found that there was no significant relationship. This indicates that 2 km ergometer rowing is not inducive of performance in 2 km on-water rowing and caution should be taken in using it as a predictive measure, it is however a common test infield. Although evidence suggests that the biochemical and metabolic demands stimulated by rowing on ergometer or on-water are similar (Mäestu *et al.*, 2005).

2.1.2.1. Anthropometric characteristics

Rowing is a mass-category based sport, which requires athletes to be of a certain body mass to row, such as lightweight (LWT) boats being capped at an average of 57 and 70 kg per rower (female and males respectively; anthropometrics in Table 2.1).

Table 2.1: Mean (SD) anthropometric measures in categories of rowers (Tanner and Gore, 2013)

Rower	Height (cm)	Body mass (kg)	Σ7 skinfold (mm)
LWT females	169 (0.4)	59.3 (1.8)	60.2 (9.3)
HWT females	-	75.5 (5.3)	82.4 (19.2)
LWT males	181.9 (2.0)	73.6 (1.2)	37.6 (4.6)
HWT males	192.4 (3.5)	91.3 (4.4)	54.0 (13.0)

Notes: LWT – lightweight; HWT – heavyweight; Σ – sum of.

Moderate to strong relationships have been reported between physical traits and 2 km performance outcomes in rowers (Appendix 11.10a; Smith and Hopkins, 2012). For example, stature (r = 0.66 – 0.76) has been used within British Rowing talent identification campaigns as a key selection criterion for new novice athletes. The height of the athlete, and as a by-product arm span and leg length, affects the stroke length that the athletes are able to produce and therefore force generated (Kleshnev, 2016).

2.1.2.2. Maximal and sub-maximal aerobic capacity

Aerobic capacity, otherwise known as maximal oxygen consumption (VO_2max), is the amount of oxygen consumed during maximal exercise. In endurance sports, such as rowing, aerobic capacity is a very important determinant to athletes' success and ability to sustain a high intensity work rate for a long period of time. In rowing, moderate to strong relationships (r =-0.68 – -0.96; 90 %CI: 1.0 – 3.7) have been established between VO_{2max} and 2 km performance (Appendix 11.10c; Smith and Hopkins, 2012) with examples for females ranging from 2.1 - 3.9 $L \cdot min^{-1}$ and males 3.4 - 5.6 $L \cdot min^{-1}$ (Yoshiga and Higuchi, 2003). The power attained at VO_{2max} and maximal PO (e.g. 152 – 260 W; Tanner and Gore, 2013) have strong to very strong relationships with 2 km performance (r =0.91-0.95, 90 %CI: unavailable; and -0.76 – -0.97, 90 %CI: 0.9 – 2.5; respectively), this is explained by the need of the athlete to sustain a high power output during races (Appendix 11.10b).

Similarly, to maximal aerobic capacity, submaximal aerobic capacity is also an important determinant of 2 km performance. Submaximal aerobic capacity is the ability to sustain a certain percentage of VO_{2max} over an extended period of time and is usually measured in power output (PO) at the aerobic (i.e. lactate threshold 1 [LT1]) and/or anaerobic threshold (i.e. lactate threshold 1 [LT2]) or at maximal steady-state lactate (MLSS) (Jürimae *et al.*, 2001). The power output at submaximal aerobic capacity has been considered a stronger predictor of endurance performance than VO_{2max}, due to rowing being very technical and a high VO_{2max} not necessarily pertaining to a rower's ability to row (Jürimae *et al.*, 2001). Conflictingly, Cosgrove (1999) found that VO_{2max} is the single best predictor of the velocity for a 2 km time-trial (r = 0.85) explaining 72% of the variability in 2 km rowing performance. In their review on physiological predictors of 2 km rowing performance, Smith and Hopkins (2012) observed strong to very strong relationships for PO and oxygen consumption measures at 1 $mmol.L^{-1}$ (r = -0.77 – -0.82, 90 %CI: 1.1 – 2.6), moderate to strong relationships (r = 0.57 - 0.93 and -0.77 – -0.83; 90 %CI: 1.8 – 2.8) with similar variables at LT1 and strong to very strong relationships (r = -0.68 – -0.94; 90 %CI: 0.9 – 3.0) with the same variables at anaerobic threshold (or LT2 or PO at 4 $mmol.L^{-1}$) with 2 km performance (See Appendix 11.10c). Power output at 4 $mmol.L^{-1}$ was observed to have the strongest relationship (r = ±0.84 - ±0.96, 90 %CI: 0.9 – 2.9) with 2 km performance, which explains why it is widely used to predict 2 km performance and monitor aerobic development within rowers.

2.1.2.3. Anaerobic capacity and power

Anaerobic capacity is the amount of energy produced via anaerobic metabolism. Several protocols have been established to estimate anaerobic capacity but is usually often determined by all-out tests lasting 30s – 3min (e.g. Wingate 30s test) or repeated tests of certain work/rest ratios (Tanner and Gore, 2013). Anaerobic power (i.e. peak power) is the instantaneous power output that can be generated by the ATP and Creatine Phosphate energy systems and is usually determined by all-out testing lasting 1-10 sec (e.g. the 5-stroke and 7-stroke ergometer power tests). As 2 km races start in a stationary position and generally involve an end spurt at the end of the race both anaerobic capacity and anaerobic power are important determinants of rowing performance as large forces are required to quickly accelerate the boat to an optimal speed and to generate larger forces at the end of the race. The importance of anaerobic capacity is demonstrated by the strong to very strong (r = -0.76– -0.89, 90 %CI: 1.0 – 2.2) relationship between 30 sec rowing ergometer Wingate test and 2 km performance (Appendix 11.10d; Akça, 2014; Smith and Hopkins, 2012). Whereas the mean power generated in the 5-stroke all out power tests has a correlation of between r = -0.78 – -0.94 (90 %CI: 2.4 – 3.1) with 2 km performance (Smith and Hopkins, 2012) (Appendix 11.10d).

2.1.2.4. Strength

Strength is an important component of rowing, and elite rowers can generate a maximal force of over 1,000 N for females and 1,350 N for men in their first stroke of a race (Tanner and Gore, 2013). Strong relationships have been determined with 1 RM for both upper and lower body (i.e. leg press and bench pull; r = -0.76 and r = -0.75; 90 %CI: unavailable; respectively) and 2 km rowing performance as highlighted in (Appendix 11.10e). As a consequence, resistance training (or otherwise known as strength and conditioning) is typically included in rowing training programmes alongside sessions designed to develop maximal and submaximal aerobic capacity and anaerobic capacity. It is generally considered that rowers undergo concurrent training to develop all these physical determinants.

In summary, the strongest physiological predictors of 2 km performance are PO at 4mmol.L^{-1}, PO_{max} over short periods (i.e. 30 sec), and the strength of the pull and push ability of muscles. Emphasising why rowing training programmes are predominantly aerobic and anaerobic training based with 2-3 complimentary strength and conditioning sessions.

2.2. Training load and performance

In order to monitor training and performance, training load is a frequently used concept. Training loads can be divided into external and internal loads. External training loads are the external training stressors placed on the athlete such as distance, duration and power output and internal training loads are the physiological and/or psychological responses that the athlete experiences to the external training stressors (e.g. heart rate, lactate production, muscle damage, oxygen consumption). Training load can be calculated by multiplying intensity, frequency, and duration. The monitoring of TL is important, as to cause a physiological adaptation conducive for an improvement in performance (i.e. supercompensation) the body must be placed under stress (Issurin, 2010). The destabilisation or deviation of stress from the norm is very important in inducing physiological, psychological and biochemical adaptations within the body and mind of the athlete to increase performance. With supercompensation enough recovery time is required to prevent the athlete from entering into non-functional overreaching which then can lead to injury, burnout and a weakened immune system (Issurin, 2010). After supercompensation climax the athletes' work capacity returns back to pre-load level unless another training stimulus is induced (Figure 2.1).

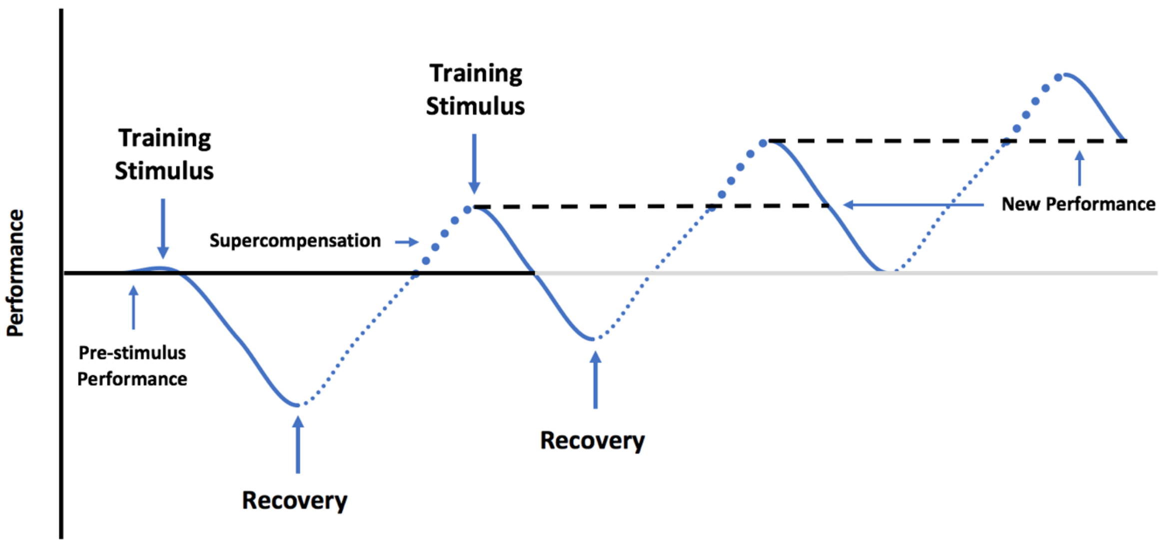


Figure 2.1: Athlete performance with training stimulus and recovery inducing supercompensation

Note: Solid figure line – training stimulus; small dotted line – recovery period; big dotted line – supercompensation period; broken line – new performance level.

The training stimulus is the external load that the athlete is exposed to and the internal load is both the physiological/psychological response to the external load as well as a stimulant for physiological and psychological adaptations to occur that are likely to improve performance. As previously mentioned, external training loads in elite rowers can be training volumes up to 20 h·wk^{-1} including distances rowed of up to 140 km·wk^{-1} (Tran *et al.*, 2015b). However, training intensity distribution has also been recognised as an important factor in determining optimal training load to gain maximal improvements in endurance performance (Guellich *et al*., 2009; Seiler, 2010). Although there are many different methods to determine training intensity distribution, one method is to separate the intensity into three zones based on two lactate thresholds, LT1 (i.e. aerobic threshold) and LT2 (anaerobic threshold): zone-1 – high volume low intensity (below LT1); zone-2 – threshold training (between lactate LT1 and LT2); and zone-3 – high intensity training (above LT2) (Seiler and Kjerland, 2006; and Seiler, 2010). This method is used in the 'polarised model of training' described previously i.e. the majority of training being in zone-1 (e.g. ~80 %) and minority of training in zones 2 (e.g. ~5 %) and 3 (e.g. ~15 %). This description stems from studies that have quantified the training intensity distribution of national and elite endurance athletes and found that their training intensity distribution generally conforms to the 80:20 polarised model (Seiler 2010; Stöggl and Sperlich 2015). It has been suggested that this polarised approach to training is effective in improving performance due to being influential in the maintenance of the autonomic balance (i.e. parasympathetic system: restorative function; and the sympathetic system: energy mobilising) (Plews *et al.*, 2014). It has been shown that national and elite rowers train for 70 - 95 % in zone-1 and 5-30 % in zone-2 and 3, with the least time in zone 2 (Stöggl and Sperlich, 2015). In Guellich *et al.* (2009), the German youth male rowers (31 international and 5 national; 19.2 ± 1.4 years; 10.9 ± 1.6 training sessions·wk^{-1}) started their basic preparation period with almost all training completed in zone-1 (95 %) and progressed to polarised training intensity distribution closer to the competition phase.

In a pilot study by Esteve-Lanao *et al.* (2007), it was reported that the sub-elite male endurance 5 km runners (regional to national level) who trained greater than 15 % training time in zone-3 showed signs of overreaching and overtraining. In the pilot study the 3-zones were determined by ventilatory thresholds, similar to the 'polarised model' that used blood lactate to distinguish between aerobic and anaerobic thresholds. It also highlighted that such highly trained endurance athletes did not gain any extra performance benefit to spend more time training in zone 2. Therefore, spending large amounts of training volume in zone 2 should only be adopted occasionally as it has been found to cause improvement in performance on a short-term basis by causing functional overreaching or supercompensation (Issurin, 2010), but maybe detrimental to performance on a long-term basis. It is acknowledged that endurance sports typically train in five training zones (Table 3.2), but for the aforementioned methods (i.e. polarised models based on lactate or ventilatory thresholds) training intensity distribution is defined by 3-zones and will be adopted in this investigation due to its association with performance in endurance based sports.

2.2.1. Training load monitoring

Quantifying internal training load

Heart rate (HR) is a widely used non-invasive measure to quantify training intensity. Banister and Calvert (1975) invented the term 'training impulse' (i.e. TRIMP) as a method to record and quantify training across any sports as an arbitrary unit. Banister's TRIMP evolved from using training HR as a percentage of HR_{max} (maximal HR) as the intensity and either duration, distance or tonnage lifted as the training volume taking in consideration HR reserve and gender (Appendix 11.2; equation 1) (Banister 1991 as cited in Borresen and Lambert, 2008). Banister's TRIMP uses the mean HR during exercise, which is the body's response to that exercise bout and will change with the next bout of training, as part of the intensity metric in the TRIMP equation. Therefore, Banister (1991) was able to establish an understanding of the dose-response of different training, therefore, allowing the method to track training load. In 1993, Sally Edwards simplified the method to a summated-HR method to quantify internal training load by multiplying the duration of training spent in 5-HR training zones by an arbitrary weighting factor associated with the zone (see Appendix 11.2; equation 2). To the authors knowledge, the Edwards TRIMP has not been validated against any blood inflammation markers or physiological responses. Lucía *et al.* (2003) modified the TRIMP further into 3 HR-zones based on the ventilatory thresholds of each athlete from prior VO_{2max} testing (see Appendix 11.2; equation 3). Lucía's TRIMP was validated between two races (i.e. Tour de France and Vuelta a España) where the distance of the races (i.e. 4352 ± 73 km and 3358 ± 56 km, respectively) as well as the daily required distances within the races differed. The researchers found that the shorter days of the Vuelta a España were more intense than the longer days (i.e. slower cycling) of the Tour de France with a higher cortisol determined after the Vuelta e España but due to the intensity difference of each days stage, the total TRIMP score for the two races (Tour de France 7111 ± 289 au and Vuelta e España 6700 ± 305 au) were similar despite a significantly longer total race time for the Tour de France. This indicates that the TRIMP method is sensitive to dose-responses of training and intensity. Both Banister's and Lucía's TRIMP use individualised parameters and relate to other metabolic pathway measures (i.e. oxygen consumption – VO_2 and blood lactate) for each athlete, while Edward's TRIMP uses zones that are not as specific to each individual athlete but related to the predicted maximum HR of the athlete. As Edward's TRIMP does not compensate for the individuality of HR responses, the subjective measurement rating of perceived exertion scale has been used instead of HR.

The rating of perceived exertion (RPE) scale was developed by Borg *et al.* (1970) as a method to determine subjective measures of exercise intensity that is experienced during exercise. The original RPE scale ranges from 6–20 where 6 = '*no exertion*' to 20 = '*maximal exertion*'. However, Borg *et al.* (1985) modified the scale to a 0-10 scale (0 = '*nothing at all*' to 10 = '*maximal effort*') i.e. category ratio 10 scale (CR-10). Foster *et al.* (2001) then modified the CR-10 (Borg *et al.*, 1985) such that '*light*' became '*easy*' and '*strong*' became '*hard*' (see Appendix 11.3). To obtain a global RPE for a specific training session, an RPE rating is collected sometime between 5 – 30 min after cessation of the training (Foster *et al.*, 2001). A session RPE training load ($sRPE_{TL}$) is then determined by multiplying this rating by the duration of training minutes (Appendix 11.2; equation 7). As RPE scales are inexpensive and easier to implement due to only requiring collecting one subjective measure after a session rather than collecting and interpreting physiological data, they have been used as an alternative measure to the HR TRIMP methods to assess training load, but still utilising the TRIMPs concept.

To determine whether $sRPE_{TL}$ is a valid alternative to HR TRIMP, Foster *et al.* (2001) examined 12 well-trained recreational level cyclists (males = 6, body mass = 70.8 ± 7.2 kg, VO_{2peak} = 54.6 ± 2.4 ml·min^{-1}·kg^{-1}; females = 6, body mass = 63.8 ± 4.3 kg, VO_{2peak}= 46.2 ± 3.4 ml·min^{-1}·kg^{-1}; Study-1) and 14 male basketball players (body mass = 89.3 ±

7.8 kg; VO_{2peak} = 51.5 ± 2.2 ml·min^{-1}·kg^{-1}; Study-2). Training loads were quantified using both the $sRPE_{TL}$ and Edwards TRIMP methods during different types of exercises (i.e. in Study-1 – steady state: 30 min, 60 min and 90 min at power output of 90 % of their individual aerobic threshold; and intervals: 5-bouts of 30 min in duration with different magnitudes of percentage mean power output [±10, ± 25, ±50 % at certain work/rest ratios; in Study-2 interval/intermittent game based) (Foster *et al.*, 2001). In both studies, there was a significant difference ($p<0.05$) between Edwards TRIMP and $sRPE_{TL}$, with $sRPE_{TL}$ providing a larger training load score. The researchers completed a regression analysis revealing a similar regression relationship between the methods and concluded that the $sRPE_{TL}$ method is a valid method to obtain internal training load but cannot be interchanged with HR-TRIMP methods. $sRPE_{TL}$ has, however, not been assessed over long periods (i.e. more than 7-weeks) of time such as a whole season. A major limitation of this study is that the $sRPE_{TL}$ is validated against Edwards TRIMP, that has not been validated itself. However, the $sRPE_{TL}$ has also been validated (i.e. significant relationships were determined, $p < 0.05$) against other validated methods that assess internal load i.e. percentage of HR peak, percentage of HR reserve, Banister's TRIMP and Lucia's TRIMP (Herman *et al.*, 2006; Impellizzeri *et al.*, 2004).

Quantifying external training load

External training load is prescribed by the coach or support staff and can be monitored when either the possibility to determine internal training load for a specific exercise (e.g. resistance training) is not valid or that other information is readily available (e.g. speed, distance). External training load can be monitored by training volume (i.e. duration) of all sessions (i.e. indoor and outdoor) using watches. For outdoor training global positioning system (GPS) trackers can be utilised to determine distances covered, speed and acceleration from the changes in location. For indoor strength and conditioning sessions on some occasions (e.g. resistance training with breaks or endurance training with light weights but continuous repetitions) it may be inappropriate to use certain internal training load measures (e.g. HR-based measures) due to a lag in the HR increase in the beginning of the exercise and the duration of resistance training exercises (Borresen and Lambert, 2009). Therefore, measures to determine external load (e.g. volume load such as tonnage lifted) that the athlete experience have been developed (Haff, 2010; Marston *et al.*, 2017). In a review on quantifying workloads in resistance training by Haff

(2010), total repetitions completed has been described as an easy method to determine training load, although this method does not take in consideration the load that is placed on the athlete. Therefore, it is better to determine the volume load for resistance training (Appendix 11.2, equation 8), by multiplying repetitions by load lifted, to determine the load placed on the athlete. However, volume load for resistance training method does not take in consideration the different metabolic demands for exercises based on the amount and mass of muscles activated (i.e. deadlift is more metabolically demanding than a bench press).

2.3. Stress and Recovery and performance

2.3.1. What is stress and recovery

Stress according to Kellmann and Kallus (2001) is defined as a deviation from the psychophysical balance (i.e. biological and psychological) norm. Whereas, recovery is defined as the time for amendment (i.e. psychologically, physiologically and socially) to re-establish performance abilities (Kallus, 1995; as cited in Kellmann and Kallus, 2001).

Internal stress and recovery reflect the subjective strain experienced on psychological (e.g. joy, depression); physiological (e.g. HR responses, respiratory, autonomic nervous system, and parasympathetic nervous system) and biochemical (e.g. blood lactate, creatine kinase) systems and the way individuals recover from the strain (e.g. relaxation, sleep). Although, external stress and recovery is the external stressors experienced (e.g. social – motivation from friends and family, and physical loads [e.g. km rowed]) which induce internal stress and recovery responses. The ‘scissors model’ (Figure 2.2; Kellmann, 1991 and 1997; cited in Kellmann and Kallus, 2001) suggested that with an increase in stress, an increase in recovery is necessary to prevent a negative stress state (i.e. with an increase in stress and the inability to meet the increased recovery demand, the athlete will experience more stress). Therefore, exercise requires the multilevel strategy to recovery (Kellmann *et al.*, 2018).

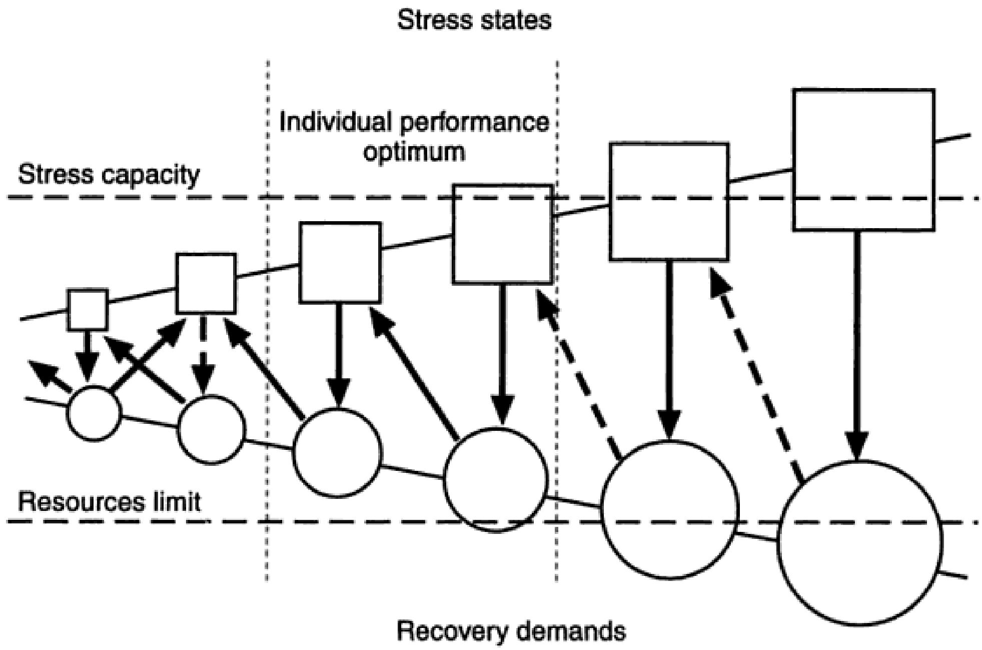


Figure 2.2: *The 'scissors model' of the interrelation between stress and recovery demands* from Kallus and Kellmann (2000); cited in Kellman and Kallus (2001).

2.3.2. How stress and recovery determine performance

Supercompensation (i.e. functional-overreaching) requires enough recovery (e.g. healing time from micro-muscle tears; mental strain; time for biochemical buffering in blood) for the adaptations to occur (see Figure 2.1). Therefore, stress and recovery within sport and training are equally important. If over time recovery is insufficient, an athlete can go into non-functional overreaching which causes underperformance and can lead to overtraining syndrome (Figure 2.3), which is associated with both physiological and psychological responses (Carfagno and Hendrix, 2014; Kellmann *et al.*, 2018). The physiological variables can include a decrease in physical work capacity, maximum HR, and increases in levels of cortisol and insomnia; psychological parameters can include lethargy, apathy and lack of competitive drive; and biochemical imbalances can occur in cortisol, creatine kinase, and cytokines.

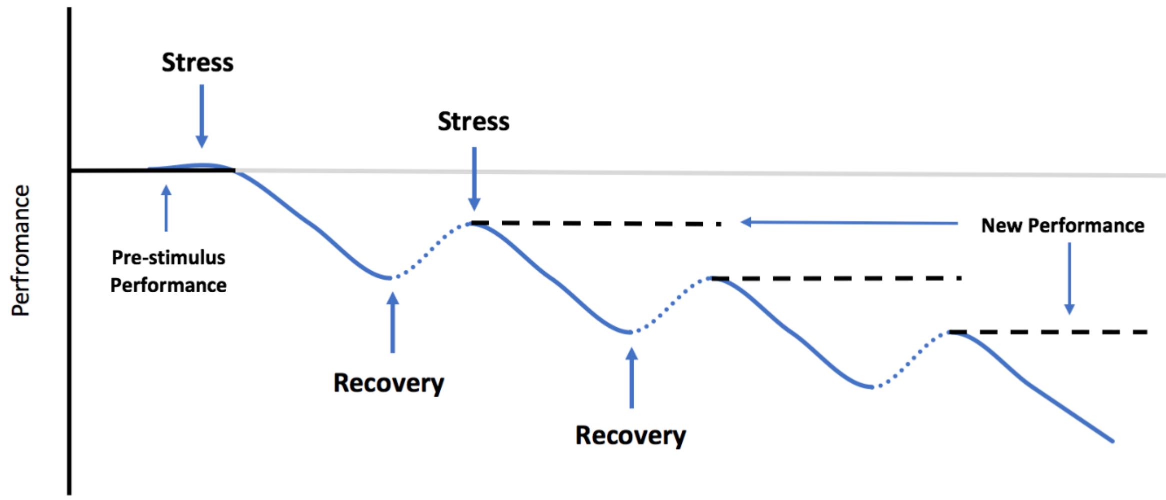


Figure 2.3: Stress-recovery state of underperformance.

Note: solid black line is stress stimulus; grey solid line is the initial performance level; dotted line is the induced recovery period; the broken line is the new performance level

Overtraining syndrome can be accentuated by other external life stressors such as assignments; examinations; social development (Dubuc-Charbonneau *et al.*, 2014). If not identified and/or treated, overtraining syndrome can lead to athlete burnout and possibly lead to an athlete to drop out from their chosen sport.

Consequently, burnout is defined as the emotional and physical exhaustion, the feeling of devaluation for oneself or the sport, a reduced athletic accomplishment and performance which can lead to withdrawal from participating in the sport (Eades, 1990 page 55; cited in Raedeke and Smith, 2001). Therefore, quality of motivation (i.e. external support and self-determined motivation) predicts the relationship to burnout dimensions: negative motivational trends had significantly higher scores on all 3 constructs (i.e. *Reduced sense of accomplishment; Emotional/physical exhaustion;* and *Devaluation*); and positive motivational trends had lower scores (Lemyre *et al.*, 2016). Lemyre *et al.* (2016) found within American elite college swimmers (f = 19; m = 25; 18-24 years) that those with increased variability in negative affect had a higher risk of experiencing burnout. To assess the prevalence of burnout in a student-athlete population, Dubuc-Charbonneau *et al.* (2014) measured perspectives of burnout in 145 Canadian student-athletes (f = 62; m = 83; 17-27 years). Of the student-athletes less than 2 % reported high scores in the burnout questionnaire. The 2 % scored high in two out of the 3 burnout constructs, which is a cause of concern for those athletes as it was during a period of low academic stress and with the added academic stress and sport demands it could increase the scores. The researchers also found that neither the type of academic program nor the year of study was related to/influenced the burnout levels of athletes. The higher prevalence of *Emotional/physical exhaustion* burnout was also reported to be greater in female student-athletes. According to Heidari (2013), who determined burnout levels in international high-performance female athletes, there are two factors that may contribute to the higher levels of burnout: i) females may be less capable of coping with physical and mental stress to their male counterparts; and ii) within the study – female athletes were less successful in international competition than their male counterparts which may have led to feelings of failure, inefficacy and reduced accomplishment. To the authors knowledge, the reasoning behind why female student-athletes experience higher levels of burnout is unknown.

Moen *et al.* (2017) suggest that athlete burnout is not necessarily predicted by the physical load or the situation but is associated with how the athlete relates cognitively and emotionally to their path towards becoming an elite athlete. Self-determined motivation has been found to be a key factor in preventing athletes from burnout (Lonsdale *et al.*, 2009).

Kellmann and Günther (2000) have shown that stress and recovery is a determining factor of performance within 11 elite rowers (female – 6: 18-30 y, 170-185 cm, 57-73 kg; male – 5: 21-32 y, 181-192 cm, 70-93 kg). Within the study, stress and recovery was measured using the RESTQ-76 inventory at 4 - 5 times during a 3-week period (i.e. on arrival; twice during training camp; once before travelling; and 8 rowers filled it in a 5th time 2-days before racing) and the performance outcomes at the 1996 Olympic games. The case-study of 2 rowers (i.e. rower A and rower B) from the study showing different recovery-stress states based on the RESTQ-76 results 9-days prior to racing. Rower A indicated a better recovery-stress state with lower stress scores in '*Somatic complaints', 'Lack of energy',* and *'Fatigue'*; and higher recovery scores in *'Self-regulation', 'Self-efficacy', 'Fitness/Being in shape',* and *'Burnout/Personal accomplishment'* presenting no limitations. Whereas, rower B showed limitations during the preparation and for the potential optimal recovery after the races. Ultimately rower A won a medal and rower B gained 13th place. This highlights the importance of recovery for athletes and including recovery-stress state as a performance factor.

2.3.3. Stress and recovery monitoring

Subjective measures:

Rating of Perceived Exertion

RPE, as mentioned in section 3.1.4, is widely used during testing and training to understand and monitor the perceived exertion that the athlete is under. However, it could be argued that RPE only assess the exertion and therefore the stress the athlete experiences internally and not the recovery and therefore does not provide a holistic picture of a balance between stress and recovery.

Questionnaires

Questionnaires are used to track the subjective stress and/or recovery the athletes encounter and have been shown to be a valid method to use on its own or with objective measures (Saw *et al.,* 2016). Commonly used questionnaires include the Recovery-Stress Questionnaire for Athletes' (RESTQ-Sport; Kellmann and Kallus, 2001); and Acute Recovery Stress Scale (ARSS) (Hitzschke et al., 2016; Kellmann, Kölling, & Hitzschke, 2016; as cited in Kellman and Kölling, 2019); and Profile of Mood State (POMS, McNair *et al.*, 1971; as cited in Raglin *et al.*, 1990).

The POMS questionnaire was originally developed by McNair *et al.* (1971; cited in Grant *et al.*, 2012) showing sensitivity to varied therapeutic situations, including rowing (Kellmann and Günther, 2000; Raglin *et al.*, 1990) and other endurance sports' (Grant *et al.*, 2012). The POMS is a 65-item questionnaire with 5 stress constructs (i.e. '*Tension-anxiety', 'Depression-dejection', 'Anger-hostility', 'Fatigue-inertia',* and '*Confusion-bewilderment')* and only one recovery (i.e. '*Vigour-activity'*). This indicates more information on negative states (i.e. stress) than the positive (i.e. recovery), and positive states are not just indicated by a lack of negative states. The POMS has been used to validate questionnaires such as the RESTQ-Sport questionnaires.

The RESTQ-Sport questionnaire was developed to measure the '*frequency of current stress along with the frequency of recovery-associated activities*' (Kellmann and Kallus, 2001). The RESTQ-Sport contains 19 constructs which are indicators of general well-being (e.g. stress - '*Emotional Stress';* and recovery - *'Sleep Quality'*) and well-being within the sport (i.e. stress - *'Fitness/Injury'*; and recovery: '*Being in Shape'*). The general well-being constructs were developed to include responses from social activities, non-specific events, work performance, emotional reactions and physical symptoms (Kellmann and Kallus, 2001). The sport-specific constructs were a continuation of the general well-being constructs. The reliability and validity testing were conducted on multiple sports (e.g. track and field, swimming, rowing) from the United States of America, Canada, and Germany with samples sizes ranging between 23-128. Specifically, the test-retest reliability of the RESTQ-76 ranges from r = 0.59 to 0.81 for a 3-day period. This indicates the questionnaires ability to assess changes in stress and recovery states that are influenced by previous days demands (i.e. psychologically and physically). The questionnaires have weak to moderate correlations for the 3-day period which indicates that the questionnaires are influenced by acute changes in daily stress and recovery, such as personal issues occurring or lack of/bad sleep, as the shared variance is only between 35 – 66 % for a 3-day period. Six case studies of seven rowers indicated that the questionnaire was sensitive to measure the changes within the rowers' recovery-stress state and allowed for intervention to be implemented which improved the stress and recovery scores significantly (Kellmann and Kallus, 2001). In the case studies interventions were implemented if i) the athletes' scores if the athletes' score were outside area of tolerance (the ± SD of the whole team); ii) if great changes are seen in responses over time; and iii) if both (i) and (ii) occur together. Such as in case study 1 the rower experienced Scores for *Fatigue* that were outside the area of tolerance for the team and low *Physical Recovery* and *Sleep Quality* scores, this lead to the conclusion that the rower was experiencing a lack of sleep (Kellmann and Kallus, 1999 as cited in Kellmann and Kallus, 2001). The coach was informed and after investigation the problem was resolved by improving the rowers' bed for more comfort (as it was deemed in bad shape), this allowed for the rowers *Physical Recovery* and *Sleep Quality* scores to improve which decreased the *Fatigue*. The RESTQ-Sport has since been validated for sensitivity to training camps, sleep disturbance, and physiological parameters (e.g. creatine kinase, cortisol, urea, and alpha-amylase) (Mäestu *et al.*, 2005; Saw *et al.*, 2016). The need for shorter questionnaires to monitor the recovery-stress states of athletes immerged as the RESTQ-76 and RESTQ-52 were too long to implement regularly to track the changes in athletes. Therefore, Hitzschke *et* *al.* (2016) and Kellmann *et al.* (2016; as cited in Kellmann and Kölling, 2019) developed the shorter questionnaires (e.g. ARSS; Hitzschke et al., 2016; Kellmann *et al.*, 2016; as cited in Kellman and Kölling, 2019) to be used on a regular basis.

The Acute Recovery Stress Scale (ARSS) questionnaire was initially developed in German and was later translated into English and validated by Nässi *et al.* (2017) (Hitzschke et al., 2016; Kellmann, Kölling, & Hitzschke, 2016; as cited in Kellman and Kölling, 2019). The ARSS consists of 32 questions across four stress constructs (i.e. '*Muscle Stress', 'Lack of Activation', 'Negative Emotional State',* and *'Overall Stress'*) and four recovery constructs (i.e. '*Physical Performance Capability', 'Mental Performance Capability', 'Emotional Balance',* and '*Overall Recovery'*). The ARSS measures the current responses in recovery-stress state of the athlete on a mental, emotional, physical, and overall levels (Kellmann and Kölling, 2019). The questionnaire has been tested for sensitivity of change in sports such as cyclists (i.e. high volume training), hockey players (i.e. 5-day training camp), and swimmers (i.e. training period and 16-day training camp) (Collette *et al.*, 2018; Kellmann and Kölling, 2019; Kölling *et al.*, 2015); and for physiological responses such as creatine kinase, granulocytes (%), and lymphocytes (%) and changes were found to have significant relationships with either stress or recovery constructs of the ARSS (Puta *et al.*, 2018). The moderate significant relationships found for lymphocyte and recovery constructs (r = 0.40), and granulocytes and stress constructs (r = 0.47) indicate that the questionnaire is somewhat sensitive to biomarker changes for training and therefore indirectly could track changes in training load (Puta *et al.*, 2018). These biomarkers are only a small part of the ARSS questionnaire due to its inability to track psychological changes (i.e. sport and personal life). The correlations are low-moderate due to the recovery-stress scales ability to interpret more than just the internal stress response from the sport, but also takes in consideration the general stress and recovery (e.g. emotional, personal, etc.) as well as the sport recovery which the biomarkers do not track. This notion is strengthened by Collette *et al.* (2018) where the ARSS was validated as a daily stress-recovery method to track the training load in 5-female high-performance swimmers (21 ± 2.8 y; 60.1 ± 6.5 kg) over a 17-week monitoring period of different periodization phases (including a 16-week training camp). Significant relationships were determined between $sRPE_{TL}$ and ARSS constructs in 5-female high-performance swimmers. In the study ARSS was completed every morning before training, and $sRPE_{TL}$ (i.e. sRPExDuration; and sRPExDistance [km]) and acute:chronic workload ratio (using $sRPE_{TL}$ methods) was determined for every training session. They found $sRPE_{TL}$, especially $sRPE_{distance}$, had the stronger relationship with the recovery-stress state of the ARSS constructs (i.e. mean cross-correlation coefficient in: *Physical Performance Capacity* = 0.39 [$sRPE^{km}$]*; Overall Recovery* = -0.36 [$sRPE^{km}$]*; Muscle Stress* = 0.41 [sRPE] and = 0.52 [$sRPE^{km}$]*;* and *Overall Stress* [$sRPE^{km}$]; less so in remaining constructs = ±0.23) than the acute:chronic workload ratio (= ±0.23).

The Athlete Burnout Questionnaire (ABQ) was developed by Raedeke and Smith (2001) to determine the psychometric testing for burnout level in swimmers, specifically, using a 21 item ABQ with constructs *'Emotional/physical exhaustion'; 'Reduced sense of [sport] accomplishment'; and '[sport] Devaluation'*. Due to the strong psychometric properties of the ABQ, the validity was demonstrated by generalising the questionnaire to other sports (e.g. basketball, cross-country, and football) in a college setting and was found to have moderate to strong relationships (*r* = 0.69 – 0.88) with competitive trait anxiety, amotivation, intrinsic motivation, enjoyment and commitment (Raedeke and Smith, 2001). This indicates that there is a shared variance of 47 – 77 % that pertained to the validity, although these are only weak to moderate relationships and may indicate that the questionnaire is not able to track all of the factors that influence burnout or that the questionnaire is not completely appropriate for sport setting as it was invented for use in clinics. As burnout is not just present in sport but also in an academic setting, the burnout levels in student-athletes are increased. Therefore, measuring burnout levels in student-athletes are important. Alongside the validation from Raedeke and Smith (2001), Dubuc-Charbonneau *et al.* (2014) examined the burnout levels in student-athletes for multiple sports and academia backgrounds at two universities in Canada and found the scale to indicate high levels of burnout in either all three constructs (1.4 % of student-athletes) or in two constructs (2 % of student-athletes). The athlete burnout has also been linked with signs of overtraining and overreaching (Cureton, 2009), and is therefore important when investigating whether a training programme is appropriate for athletes.

2.4. Training adherence and performance

Adherence and performance in sport is still under researched and the evidence surrounding this topic is related to health and well-being. Training programmes are prescribed to stimulate the athletes physiological and psychological systems to induce adaptations for better performance (see section 2.2). Therefore, adherence is perceived as an important factor in the performance of an athlete. Taking into consideration the individuality of training load, performance may be dependent on the athlete adhering to the programme and whether the programme is suitable for the athlete.

2.5. Injury and illness and performance

Rowing is a repetitive movement sport, where the movement of the rowing stroke is repeated to propel the boat forward over the distances required. To ensure the athlete becomes effective and efficient at the rowing stroke, the rower performs large volumes of training using this repetitive movement. Therefore, it is not surprising that the most common injuries are caused by overuse (Hosea and Hannafin, 2012). Overuse injuries have been reported to represent 73.8 % of injuries and are generally caused by abrupt changes in training volume and/or alterations in either the rower's technique or the type of boat they are rowing (e.g. scull to sweep, single boat to crew boat of 8) (Murray, 2017; Smoljanovic *et al.*, 2009). This indicates the importance of tracking training load to monitor/prevent injury and overtraining. Most common overuse injuries in rowing are located in the lower back (e.g. bulging disc), hips (e.g. femoroacetabular impingements), ribs (e.g. stress fracture, intercostal muscle strain) and the forearm/wrist (e.g. exertional compartmental syndrome) (Hosea and Hannafin, 2012). Smoljanovic *et al.* (2009) also found that female rowers have a higher prevalence of injury (1.1 injury per rower) than male counterparts (0.9 injuries per rower).

Likewise, overtraining may cause athletes to experience a weakened immune system (Mackinnon, 2000), psychosocial stress and lack of sleep (Schwellnus *et al.*, 2016). The weakened immunity is associated with frequent acute illness, especially in the upper respiratory tract (Mackinnon, 2000). The athletes' immune system can be suppressed for several hours after an acute bout of intense exercise due to suppression of lymphocyte and the counter increase in cytokines causing a reduction in the cell-mediated immunity which leaves the athlete vulnerable to infection (Nimmo and Ekblom, 2007). Both injury and illness may cause training sessions to be missed, which will decrease the performance and/or the development of the athlete.

2.6. Summary

In summary, rowing is a physically demanding strength-endurance sport that requires a high energy demand from the start of a 2 km race to accelerate from stationary to an optimal speed. As the rowing training programme is based predominantly on aerobic and anaerobic training with complimentary resistance sessions for strength, adherence to the programme is important for adaptations. Therefore, physiological determinants such as PO at 4 mmol·L^{-1} blood lactate, PO_{max} of short duration (<1 min), and push and pull ability of muscles are important to predict 2 km rowing performance. Training can be monitored using training load, and due to the recovery-stress scales having relationships with physiological, psychological and biochemical markers it is assumed that the questionnaires should be able to track training load. Monitoring training load and burnout levels is important to prevent injury (e.g. overuse injuries) and illness (e.g. weakened immune system) of athletes consequently causing a loss of training time and adherence that can ultimately effect performance. Therefore, it is hypothesised that recovery-stress scales (i.e. ARSS) will be able to track training load and subsequently both be able to track the performance changes of the well-trained female UK student-athlete rowers.

3. Methods

3.1 Ethics

The study undertaken received ethics approval from Oxford Brookes University Research Ethics Committee. Before the commencement of the study, after reading a participant's information document, participants gave their written informed consent to participate.

3.2 Participants

Fourteen female rowers (13 undergraduates and one postgraduate) from the Oxford Brookes University female rowing team participated in the study. The rowers were coached by the Oxford Brookes coaches and followed their prescribed training programme. However, in weeks 8 and 9, one participant followed a different programme set by the GB rowing U23 National coach. Due to incidences of non-compliance, data was collected for 11 participants for $sRPE_{TL}$ (see section 3.7.1.2 for method); and for all 12 participants data was collected for HR_{TL} (see section 3.7.1.1 for method), volume load of resistance training (see section 3.7.2.1 for method) and for the subjective measures of stress and recovery and burnout (see section 3.8 for methods). The mean characteristics of the 12 participants are displayed in Table 3.1. There are weeks where the number of participants are less for reasons such as: technical failure of HR equipment (e.g. HR data not recorded correctly; watch was too low on battery to record session; HR strap out of battery); and information unable to be used (e.g. too many HR values recorded incorrectly in a week so has to be excluded).

Table 3.1: Mean (SD) participant characteristics

Participant	Age (years)	Height (cm)	Body mass (kg)	Body fat (%)	2 km Performance (Watts)	2 km Performance (min:sec)
Mean (SD)	20 (1)	178.3 (7.9)	78.4 (7.3)	21.4 (3.7)	274 (22)	01:49.0 (00:02.9)

Prior to commencement in the study, participants completed a Physical Activity Readiness Questionnaire (PAR-Q). The inclusion criteria were i) participants had to be female aged between 18 – 40 years of age; ii) an experienced rower (i.e. rowing >2 years of 3 sessions per week or >1 year of 5 rowing specific training sessions per week); and iii) injury free on commencement of study.

3.3 Experimental design

The study is based on describing the training responses to the training set by the rowers' coach, therefore, the training completed was not altered by the researchers. The study is part of a 28-weeks longitudinal study, with the first 18-weeks being reported within this study.

Prior to study commencement, participants' height, body mass, and body fat percentage were measured. Initial levels of recovery-stress, burnout and academic stress were also measured. In week 2, lactate threshold was determined using an incremental exercise test on a Concept II rowing ergometer. The participants were then monitored over a 15-week period that was split into 3 periods: 1 – general preparation (weeks 1 - 5[1]); 2 – Christmas holiday (weeks 5 - 7); 3 – pre-competition (week 8 - 15) (Figure 3.1). The monitoring week started on the Thursday and ended on the following Wednesday of every week. Daily measures of duration of training, distance covered, HR, sRPE and tonnage lifted were recorded to quantify training load. Adherence was recorded on a weekly basis. Recovery-stress states, academic stress, and burnout were recorded on either a weekly basis or quarterly basis. Submaximal performance (i.e. 30 min all-out erg) and 2 km performance were also measured at certain points during the 18-week period. The athletes were required to follow the training schedule set by the coaches during weeks 1 - 5 and weeks 8 - 15. During the Christmas holiday period the athletes were provided with a list of exercises (e.g. Strength and conditioning, ergometer, run, cycle, rowing on water) that they could choose from and complete for 45 min per day (excluding the 25th Dec and 1st Jan). At the end of the study period, post study exit interviews were held to determine the accuracy of the information the participants provided (i.e. accuracy of subjective measures, injuries reported and performance measures provided by the coach and estimated percentages of sessions recorded). The participants were also asked about their experience of participating in the study (summary in Appendix 11.4).

[1] General preparation phase was from week 1 to Sunday of week 5 where the Christmas holiday phase started on the Monday in week 5 to the end of week 7, therefore week 5 is present in both phases.

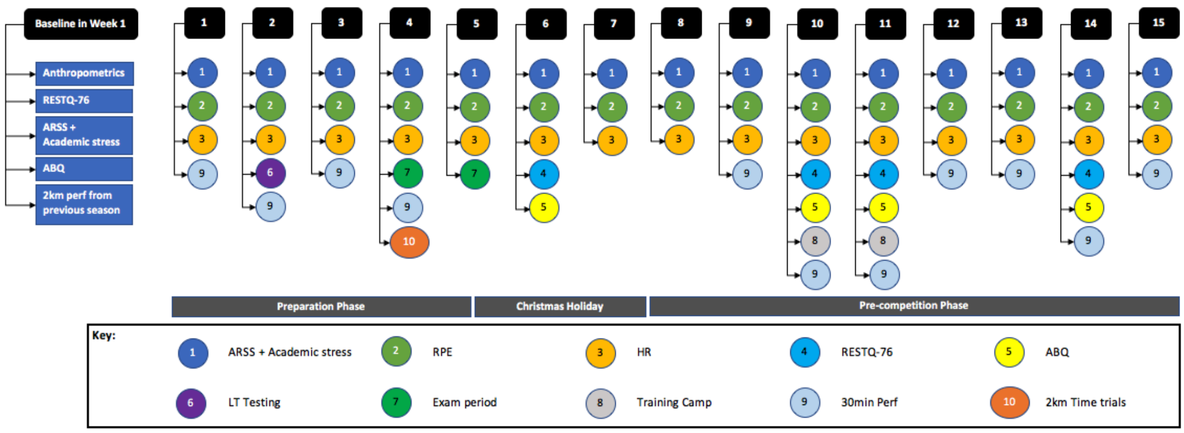


Figure 3.1: Schematic figure of events during the 15-week monitoring period

3.4 Anthropometric measures

Participants' heights were measured using a metal stadiometer (Holtain Limited). Participant's body mass and body fat percentage were measured using a bioimpedance scale (Tanita: BC-418 Segmental body composition analyser; Japan).

3.5. Physiological measures

A sub-maximal incremental exercise test was completed in week 2. The test involved participants completing a 10 minutes warm up (at an intensity of 45 - 50 % of most recent 2 km performance). Then after a 5 minute rest, the participant completed 6 four-minute stages (individual step progressions are 55, 60, 65, 70 & 75 % of the athlete's most recent 2 km ergometer test average power; at stroke rates (±1) of 18, 20, 22, 24, 26; respectively) with 45 sec passive rest in between (Tanner and Gore, 2013). At the end of each stage measurements of power output (PO), HR, blood lactate (B_{LA}) and RPE (Appendix 11.3) were recorded. Earlobe capillary blood samples were assayed for B_{LA} using a Biosen C-line (EFK Diagnostic Holdings plc; Cardiff, UK). Aerobic threshold (LT1) was determined using the ADAPT (automated data analysis of progression test; defined as the B_{LA} point before the first inflection of more than 0.4 mmol.L^{-1} B_{LA}) method for LT1 (aerobic threshold) using software developed by Newell *et al.* (2007), in addition two observers confirmed LT1 based on the visual graph as well as the B_{LA} determined at each stage of the test. Due to only 9 out of the 12 rowers attaining high enough PO in the last two stages it was inaccurate to estimate the remaining 3 rowers' anaerobic threshold (LT2) to use in individual training load equations. Therefore, only associated HRs to LT1 were used to calculate the individual training intensity distribution according to Seiler and Kjerland (2006).

3.6. Performance measures

During the weeks of 1-4 and 9-15, the rowers completed once a week (i.e. every Monday pm) an exercise bout of 30 min on the rowing ergometer, with the coach instructing to complete the bout at a maximal sustainable level/split for 30 minutes. Due to the duration and instruction of the exercise bout, the intensity (i.e. mean power output attained during the 30 minutes) of this session is theoretically an indirect measurement of a rower's anaerobic threshold (LT2) (Tanner and Gore, 2013). This is evidenced by the GB Rowing Training Matrix and the AIS as seen in Appendix 11.11 and Table 3.2., respectively (personal correspondence with Dr Sarah Davey; Tanner and Gore, 2013). The mean power of each participant 30 min effort (PO_{30}) was recorded every week and used to assess the participant's performance in training and aerobic development.

As part of their training programme, participants completed three 2 km time trials on a Concept II rowing ergometer at week-0, week-4 and week-18 with the mean power output during the trial recorded (PO_{2km}). The 2 km performance trial performed at week 18 has been included in this study as it was deemed to reflect the response to training over the 15-week period monitored in this study. This measure was used to assess participants response to training and as previously described (section 2.1.1) to indirectly measure improvements in on-water 2 km performance.

3.7. Assessment of training load

3.7.1 Physiological measures of internal training load

3.7.1.1. Heart rate monitoring of aerobic and anaerobic based sessions

Participants were provided with a GPS sports watch (Polar M400; Polar Electro Oy, Kempele, Finland) and corresponding heart rate sensor to record the HR, duration and distance of every training session. The sports watch also allowed participants to identify the mode (e.g. rowing ergometer, on water, indoor cycling, swimming, running) of each training session. On a daily or weekly basis, participants downloaded the training information from the sports watch using Polar's 'Polar Flow' application (version 3.0.0.1337). Using the Polar coach application, the raw data for each training session was downloaded and the HR's associated with each participants' estimate of lactate threshold (see section 3.5) were used to determine the HR intensity for participants' training intensity distribution (see Appendix 10.2, equation 4 and 5).

The age-predicted estimate of HR_{max} and percentages of HR associated with the aerobic and anaerobic thresholds (LT1 and LT2) (Faude *et al.*, 2009; Bourdon, as cited in Tanner and Gore, 2013; in Table 3.2) were used to calculate an HR TRIMP (Appendix 11.2, equation 6) using Banister's TRIMP concept. The HR_{TL} method only applies to aerobic training or steady state training (i.e. training in zones 1 – 5) and not to the sessions defined outside of these parameters (i.e. resistance training) due to the delay of HR response to high intensity interval training.

Table 3.2: Classification of Training Zones as a Function of Lactate threshold 1 and Lactate threshold 2 (Tanner and Gore, 2013; AIS book) with adaptations from GB rowing Training Matrix

Training zone	Prescribed description	Blood lactate threshold relationship	Blood lactate concentration (mmol/L)	%HRmax	%VO2max	Rating of perceived exertion	Duration capable endurance athletes (h:min:s)	Duration capable rowers (h:min:s)	Adaptations (i.e. increases in) *
T1 - UT3	Light aerobic	<LT1	<2.0	60-75	<60	Very light	>3h	>3h	Does not provoke significant physiological adaptations to occur
T2 - UT2	Moderate aerobic	Lower half between Lt1 and LT2	1.0-3.0	75-84	60-72	Light	1-3h	1-3h	Blood volume; use of fat as fuel; aerobic enzyme activity; maximal cardiac output; capillarisation; use of lactate as a fuel; and maximal ventilatory capacity
T3 - UT1	Heavy aerobic	Upper half between LT1 and LT2	2.0-4.0	82-89	70-82	Somewhat hard	30-90min	20min/h	Blood volume; use of fat as fuel; aerobic enzyme activity; maximum cardiac output; capillarisation; use of lactate as a fuel; maximum ventilatory capacity; improved buffering capacity; maximum rate of glycogen use; and race specific neuromuscular adaptations
T4 - AT	Threshold	LT2	3.0-6.0	88-93	80-85	Hard	20-60min	12-30min	Blood volume; aerobic enzyme activity; maximum cardiac output; capillarisation; use of lactate as a fuel; maximum ventilatory capacity; improved buffering capacity; maximum rate of glycogen use; and race specific neuromuscular adaptations
T5 - TR	Maximal aerobic	>LT2	>5.0	92-100	85-100	Very hard	2-12min	5-8min	Aerobic enzyme activity; maximum cardiac output; capillarisation; use of lactate as a fuel; maximum ventilatory capacity; improved buffering capacity; and race specific neuromuscular adaptations

*Note: Tn – Zones; LT1 – lactate threshold 1; LT2 – lactate threshold 2; * - from GB rowing training matrix.*

3.7.1.2. Subjective measures of internal training load

Sessions rating of perceived exertion (sRPE) were utilised as a subjective assessment of the intensity of the session and subsequently used to calculate session rating of perceived exertion training load ($sRPE_{TL}$). Using the method from Foster *et al.* (2001), $sRPE_{TL}$ was determined for every session using the sRPE score multiplied by the duration (Appendix 11.2, equation 7). To avoid influencing each other's measures, the participants were advised not to share their RPE score with each other and manually entered ratings after each session on individual provided sheets which were collected weekly or bi-weekly from participants.

3.7.2. External training load:

3.7.2.1. Strength and conditioning sessions training load

As HR is not considered a true representative of the training load completed during strength and conditioning training (Borresen and Lambert, 2009), a modified volume load for resistance sessions based on the training load equation was used instead to determine external training load (Haff, 2010; Appendix 11.2, equation 8). The weighting factors were determined by the collaboration of two professional strength and conditioning coaches who have 3-years' experience working within rowing (Appendix 11.12). Therefore, the weighting factors cannot be translated to other populations. Furthermore, adjustments were made to certain body weight exercises by athletes to allow completion of the exercise (Appendix 11.2, equation 10). The estimated percentages for resistance bands used for adjustments are arbitrary and have been based on tacit knowledge as opposed to experimental data, but do indicate smaller values for volume load as the participants were unable to complete the exercises with their own strength (Appendix 11.2, example-1).

3.7.2.2. Aerobic outdoor sessions external training load

The duration of all sessions and distance of outdoor training was recorded by the sport watches (section 3.6.1.1.). Sport watches have an accuracy of within 0.6 ± 0.3 to 1.9 ± 1.5 % of the actual distance in marathons, including the Polar M400 watch, making it a reliable and valid method to track distance (Johansson *et al.*, 2020). Outdoor training consisted of on water rowing, running, and cycling. Duration was used as an indirect external load factor to assess the sensitivity and therefore validity of the training load and stress and recovery measures.

3.8. Stress and recovery, burnout and academic stress

Athletes were required to complete 3 different types of questionnaires over the 15-week period (as seen Figure 3.1): the Athlete Burnout Questionnaire (ABQ; Raedeke and Smith, 2001) in weeks 1 and 14; Recovery and Stress Questionnaire for Sport 76 (RESTQ-Sport76) (Kellmann and Kallus, 2001) in weeks 1, 6, 10, and 14; and Acute Recovery and Stress Scale (ARSS; Nässi *et al.*, 2017) with academic stress (from Perceived Academic Stress scale; PAS; Bedewy and Gabriel, 2015) questions on a weekly basis. The questionnaires were administered using online Google Forms and rowers were prompted to complete the forms via SMS. The ARSS was administered on a Wednesday which is mid-week academically and signified the end of a monitoring week; the RESTQ-76 and the ABQ were administered on a Friday to prevent questionnaire burnout. RESTQ-76 was used to provide a more in-depth evaluation of what constructs were affected during any peaks in the constructs associated with stress and recovery measures by the ARSS questionnaire. ARSS questionnaires were completed before or 3 after hours after the training session set for that day.

The ARSS (Nässi *et al.*, 2017) and the RESTQ-76 (Kellmann and Kallus, 2001) were scored on a 7-point Likert scale where 0 = *does not apply at all/never* to 6 = *fully applies/always* (respectively; Appendix 11.5. and 11.7). Recovery scores were best when high (score of 3–6) indicating highly recovered, whereas stress scores were best at the lowest (score of 0–3) indicating less stress. In both scores, 3 is seen as a more neutral score and is considered as a favourable score.

Four academic stress questions were added to the ARSS to assess the academic stress of the athletes. Questions were taken from 2 constructs from the PAS scale (Bedewy and Gabriel, 2015): *Perception of workload* construct (i.e. *2. The time allocated to classes and academic work is enough;* and *4. Even if I pass my modules, I am worried about getting a job*) and *Time restrain* construct (i.e. *1. I believe that the amount of work assigned is too much;* and *3. I have enough time to relax after work*) (Appendix 11.6). The questions were scored based on a 5-point Likert scale where 1 = *strongly disagree* to 5 = *strongly agree*. Unlike in the full PAS, one question from each construct (i.e. questions 2 and 3) were reverse scored due to conflicting scoring directions for positive scores. Therefore, a score below 3 indicates less academic stress.

Similarly, the 15 question ABQ (Raedeke and Smith, 2001; Appendix 11.8) only has 3 constructs: *Reduced sense of accomplishment* (RA)*; Emotional/Physical exhaustion* (E)*;* and *Devaluation* (D). The scoring works similarly with a 5-point Likert scale where 1 = *almost never* to 5 = *almost always*. Change over time was scored similarly to Dubuc-Charbonneau *et al.* (2014) where a score of 3 or higher is seen as experiencing high levels of burnout.

3.9. Adherence

For each training session completed on the rowing ergometer and on water the coach kept an adherence score for each athlete based on whether they completed the full training that the coach has prescribed. The scoring system is: -1 = *extra training on top of prescribed training*; 0 = *full prescribed training complete*; 1 = *full volume with modified modality;* 2 = *reduced volume* ± *modality*; and 3 = *no training complete*. The total of the adherence score was then transformed into a percentage of adherence, as seen in Appendix 11.2, equation 11.

3.10. Statistical Analyses

All statistical analyses were performed using SPSS version 25.0. Data are presented as mean ± standard deviation. One-way Repeated Measures ANOVA were used for internal and external training loads, adherence, and recovery-stress scales by: i) initially using Holms Bonferroni post hoc test for all available weeks; and ii) by selecting weeks with greatest fluctuations (weeks: 1, 4, 5, 7, 8, 10, 13, 14) and completing Bonferroni post hoc test to indicate where the significance was established. Even though more significant differences were found in the latter, to reduce researcher bias the results from the Holms Bonferroni post hoc test are reported. Paired T-tests were used to asses changes in the performance measures differences (baseline – best wattage) and the athlete burnout questionnaire. To assess the relationships between variables, Pearson correlation coefficient or Spearman's rho (correlations including academic stress, PO_{30} and adherence) were utilised on the average results of each variable over the 15-week period. Effect size for main effect results are presented as partial eta-squared (η_p^2) for One-way Repeated Measures ANOVA and as Cohen's *d* (*d*) for paired

T-tests. Confidence interval was set at ±95 % with alpha value of $p < 0.05$. Research with the ARSS questionnaire and training load includes 5 (Collette *et al.*, 2018) to 23 (Reader *et al.*, 2016) participants. Therefore, the intent was to have at least 23 participants, but only 14 agreed to take part in the current study.

4. Results

4.1. Description of training practices

The duration of training and sessions per phase were: preparation phase (weeks 1 - 5) – 8.1 ± 2.2 h·wk^{-1} for 11 ± 4 sessions·wk^{-1}; holiday phase (weeks 5 - 7) – 4.7 ± 2.6 h·wk^{-1} for 7 ± 4 sessions·wk^{-1}; pre-competition phase (weeks 8 - 11) – 10.9 ± 2.4 h·wk^{-1} for 15 ± 4 sessions·wk^{-1}. Overall athletes adhered 81 ± 7 % to the prescribed training.

4.1.1 Mode of training

The percentage in mode is only completed up to week 11. There was no main effect of time ($p > 0.05$) determined for any mode of training. In weeks 1 - 5 and 8 - 11 the athletes completed most of the training on water rowing (*Row*; 46 and 52 %; respectively) ergometer training (*Erg*; 22 and 13 %; respectively) and the remaining time being composed of strength and conditioning (*S&C*; 23 and 22 %; respectively) and other training (*Other*; 9 and 14 %; respectively) (Figure 4.1). Whereas, in weeks 5 - 7 during the Christmas holidays period this distribution changed to *Row* (23 %), *Erg* (20 %) and *S&C* (18 %) training vs. *Other* (39 %) training. There were only significant differences determined between modes *Other* and *Erg* in weeks 2, 4, 7, 8, 10, and 11; and *Other* and *Row* in weeks 3, 4, 6, 7, 9, 10, and 11 (Figure 4.1).

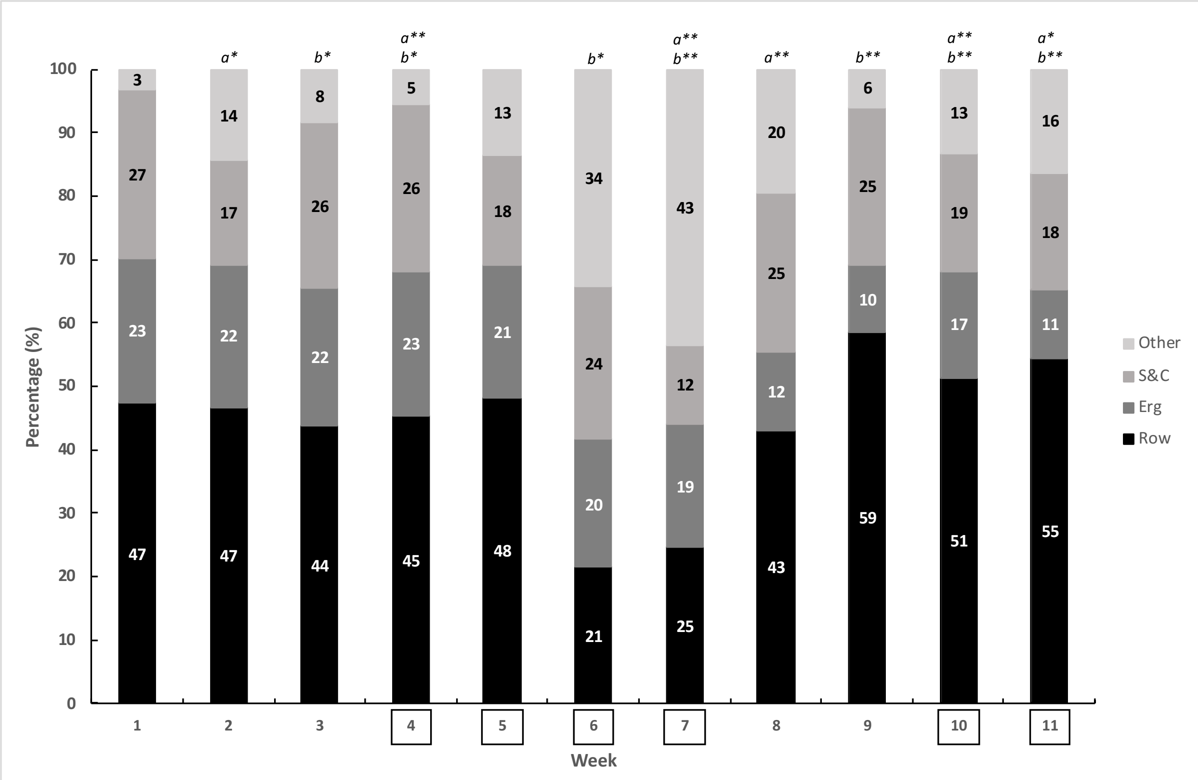


Figure 4.1: Mean percentage of time spent in modes of training over 11-week period

*Note significant difference between: a – 'Other' and 'Erg'; b – 'Other' and 'Row'; * - p < 0.05; and ** p < 0.01. Events in weeks: 4 – British rowing trials; 4 to 5 – university exam period; 5 to 7 – holiday; and 10 to 11 – 3-day training camp. n – number of participants week: 1 n = 6; 2 n = 10; 3 – 7 and 9 n = 12; 8 and 10 – 11 n = 11.*

4.1.2. Training intensity Distribution

The HR training intensity distributions is only completed up to week 11. There was a significant main effect of time on both HR training intensity distribution below aerobic threshold (F (10, 40) = 3.120, p = 0.005, η_p^2 = 0.438) and HR training intensity distribution above aerobic threshold (F (10, 40) =3 .137, p = 0.005, η_p^2 = 0.440), but the Holms Bonferroni pairwise comparison could not detect where any differences existed between weeks due to a small sample size and large variance between participant results (Table 4.1). The athletes completed 51 ± 4 % of their aerobic training below and 49 ± 4 % above their individual LT1 (Figure 4.2).

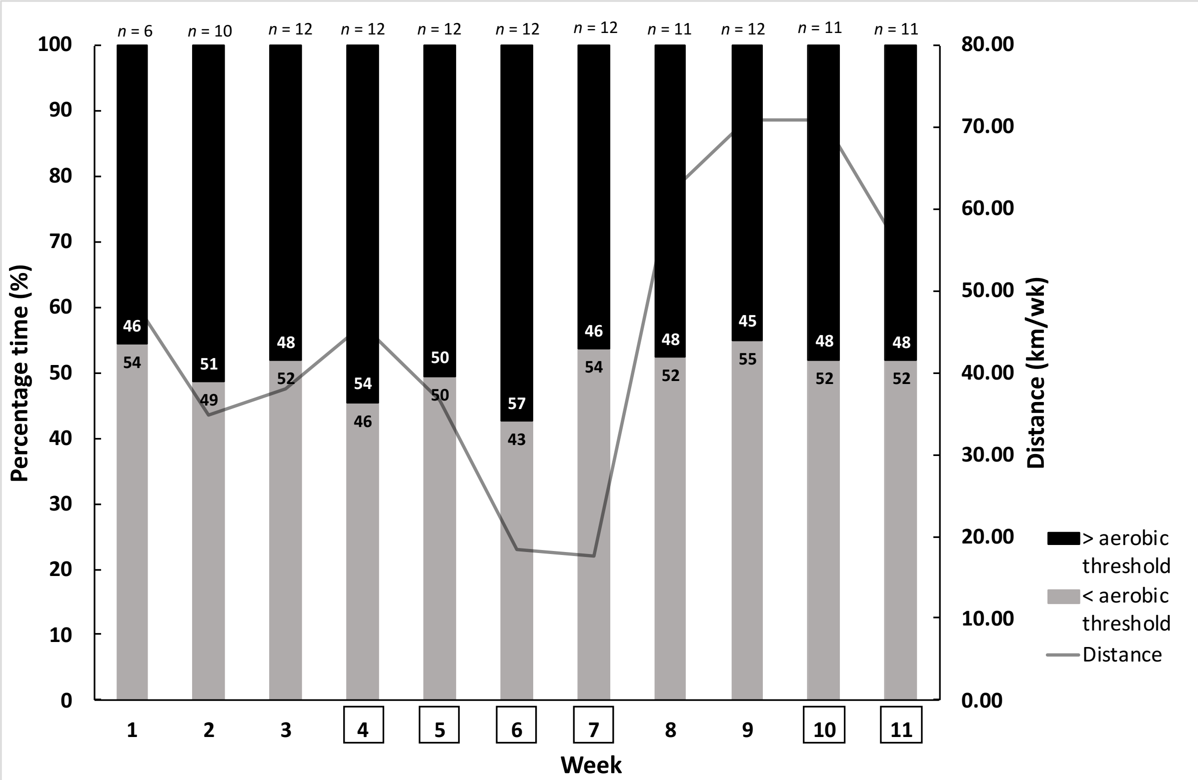


Figure 4.2: Mean percentage of time for aerobic HR training intensity distribution and distance of weekly training

>LT1 – training above lactate threshold; <LT1 – training below lactate threshold; and n – number of participants. Events in weeks: 4 – British rowing trials; 4 to 5 – university exam period; 5 to 7 – holiday; and 10 to 11 – 3-day training camp

Table 4.1: Mean (SD) of variables with a significant main effect of time over the 15-week monitoring period

Variable	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
Duration (min)	506 (121)	553 (120)	467 (170)	472 (78)	399 (181)	327 (155)	**236 (153)** [b]	711 (15)	**763 (76)** [c, g]	**772 (89)** [g]	638 (138)	642 (109)	591 (182)	**562 (131)** [j]	483 (182)
Duration (h)	8 (2)	9 (2)	8 (3)	8 (1)	7 (3)	5 (3)	**4 (3)** [b]	12 (4)	**13 (1)** [c, g]	**13 (1)** [g]	11 (2)	11 (2)	10 (3)	**9 (2)** [d, f]	8 (3)
Distance (km)	49.2 (9.8)	34.8 (19.7)	38.0 (14.5)	46.0 (6.2)	36.7 (26.5)	18.4 (26.1)	17.7 (14.0)	62.1 (39.2)	70.9 (23.9)	**71.0 (17.8)** [g]	55.0 (19.9)	-	-	-	-
HR TID <LT1* (min)	271 (95)	349 (131)	289 (145)	288 (167)	232 (151)	165 (130)	170 (120)	410 (167)	444 (149)	486 (264)	347 (159)	-	-	-	-
HR TID >LT1* (min)	228 (128)	369 (85)	268 (141)	345 (149)	236 (75)	222 (152)	147 (99)	373 (168)	363 (140)	449 (199)	323 (175)	-	-	-	-
HR_{TL}* (au)	687 (141)	789 (103)	591 (278)	638 (226)	501 (205)	358 (209)	283 (211)	944 (424)	910 (197)	997 (324)	704 (250)	-	-	-	-
$sRPE_{TL}$ (au)	-	-	-	-	-	1292 (771)	1109 (1144)	3278 (2292)	**4079 (1074)** [f, g]	**4056 (1207)** [g]	**3508 (716)** [f, g]	3181 (1377)	3036 (1191)	3362 (1152)	3307 (1746)
$VL_{resistance}$ (au)	6666 (3185)	6502 (2421)	8716 (2585)	7482 (2919)	**3277 (1646)** [a, b, c, d,]	-	-	**16749 (1558)** [a, b, c, d]	**16511 (2449)** [a, b, d]	15493 (4598)	10348 (4402)	8818 (4624)	-	-	-

*Note: Main effect of time was measured between weeks: 1, 4, 5, 7, 8, 10, 13, and 14. HR TID <LT1 – heart rate training intensity distribution below aerobic threshold; HR TID >LT1 – heart rate training intensity distribution above aerobic threshold; HR_{TL} – heart rate training load; $sRPE_{TL}$ – sessions rating of perceived exertion training load; $VL_{resistance}$ – volume load for resistance training, au – arbitrary units. Significant difference ($p<0.05$) compared to: a – week 1; b – week 4; c – week 5; d – week 7; e – week 8; f – week 10; g – week 13; h – week 14; and * - Holms Bonferroni pairwise comparison could not detect where the differences were due to variance of responses between participants.*

Table 4.1 (Cont.): Mean (SD) of variables with a significant main effect of time over the 15-week monitoring period

Variable	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
ARSS S1	3.56 (0.59)	3.83 (1.07)	3.00 (1.08)	3.85 (0.79)	2.85 (1.00)	2.29 (1.00)	2.29 (0.95)	**4.30 (0.56)** [a]	3.59 (0.66)	3.79 (0.70)	3.46 (0.66)	3.58 (1.01)	3.50 (0.75)	3.41 (0.80)	3.43 (0.56)
ARSS S3	2.56 (0.72)	2.50 (0.74)	3.39 (1.29)	3.02 (0.88)	2.04 (1.39)	1.33 (0.98)	**1.69 (0.92)** [d]	2.27 (0.96)	2.91 (1.01)	2.21 (0.76)	2.35 (0.99)	2.25 (0.78)	2.96 (1.11)	3.07 (0.79)	**2.75 (0.84)** [g]
ARSS S4*	3.65 (0.62)	3.85 (0.99)	3.77 (0.70)	4.25 (1.16)	2.77 (1.69)	2.04 (1.10)	2.19 (1.26)	4.16 (0.96)	4.11 (0.88)	3.73 (1.05)	3.33 (1.20)	3.13 (1.06)	3.67 (1.01)	3.59 (1.01)	3.52 (0.89)
ARSS R3*	3.54 (0.38)	3.35 (0.69)	2.68 (0.64)	2.82 (0.84)	3.94 (0.95)	4.17 (0.97)	3.44 (0.84)	3.23 (1.02)	2.70 (0.85)	3.38 (0.72)	3.38 (0.90)	3.15 (0.66)	2.79 (0.82)	2.68 (0.58)	2.86 (0.73)
ARSS R4*	2.35 (0.64)	2.28 (0.70)	2.52 (0.83)	2.02 (0.84)	3.15 (1.45)	3.98 (1.08)	3.81 (0.93)	2.23 (0.85)	2.14 (0.90)	2.35 (1.10)	2.92 (0.79)	2.73 (1.09)	2.77 (0.96)	2.39 (0.63)	2.55 (0.55)
PAS Time Restraint*	3.42 (0.73)	2.95 (0.60)	2.73 (0.82)	2.73 (1.08)	2.54 (1.08)	2.50 (0.93)	2.54 (0.94)	2.45 (0.88)	2.45 (1.25)	2.42 (1.06)	2.92 (1.06)	2.60 (0.88)	2.79 (1.03)	2.77 (1.17)	2.86 (1.07)

*Note: Main effect of time was measured between weeks: 1, 4, 5, 7, 8, 10, 13, and 14. ARSS – Acute Recovery Stress Scale; ARSS S1 – Muscle Stress; ARSS S3 – Negative Emotional State; ARSS S4 – Overall Stress; ARSS R3 – Emotional Balance; ARSS R4 – Overall Recovery; PAS – Perceived Academic Stress scale. Significant difference (p<0.05) compared to: a – week 1; b – week 4; c – week 5; d – week 7; e – week 8; f – week 10; g – week 13; h – week 14; and * - Holms Bonferroni pairwise comparison could not detect where the differences were due to variance in responses between participants*

4.1.3. Training duration and load

There was a significant main effect determined for distance (F (10, 40) = 3.258, p = 0.004, η_p^2 = 0.449) between weeks: 7 and 10 (p = 0.001, 53 ± 16 km) (Table 4.1).

There was a main effect of time for HR_{TL} (F (10, 40) = 7.515, p < 0.001, η_p^2 = 0.653) for available weeks (1 - 11) (Figure 4.3), but the Holms Bonferroni pairwise comparison could not detect where any differences existed between weeks (Table 4.1).

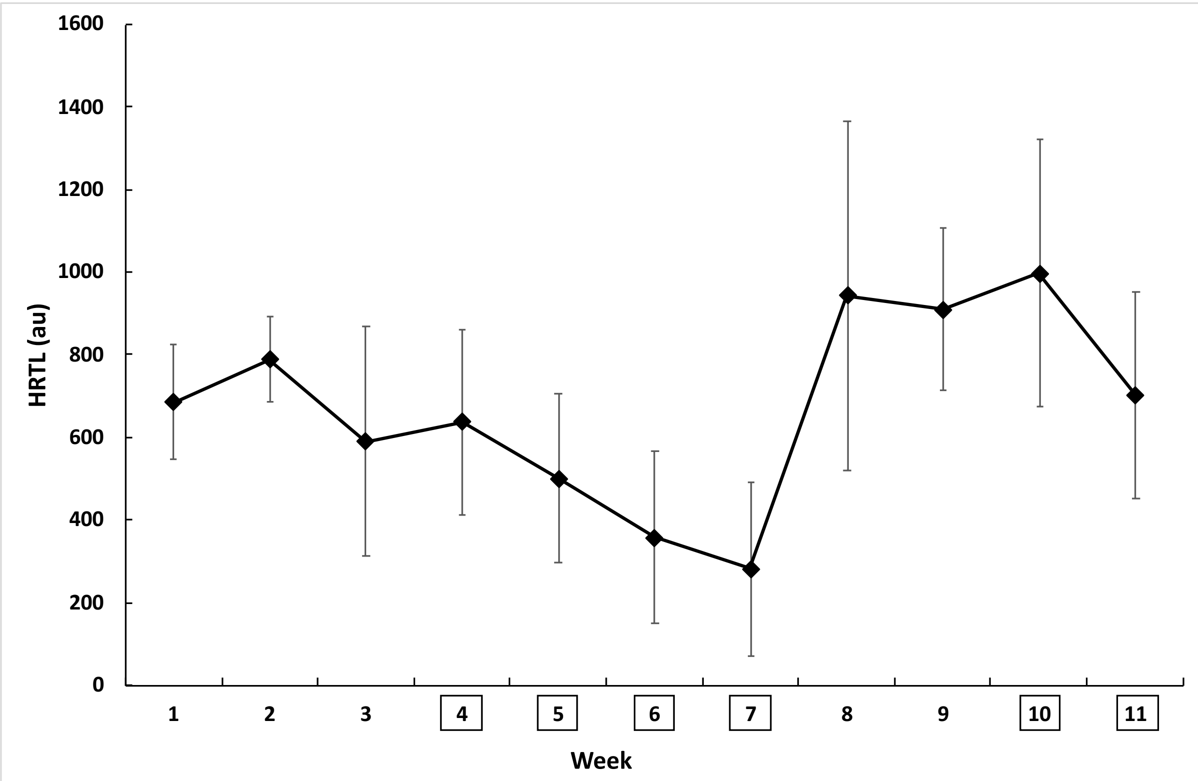


Figure 4.3: Mean (SD) changes in HR_{TL} over the 11-week training period

Events in weeks: 4 – British rowing trials; 4 to 5 – university exam period; 5 to 7 – holiday; and 10 to 11 – 3-day training camp.

Similarly, for the available weeks (6 - 15) a significant main effect of time was determined for $sRPE_{TL}$ (F (9, 54) = 4.722, p < 0.001, η_p^2 = 0.440) with changes detected between weeks: 6 and 9 (p < 0.001, +2787 ± 296 au); 6 and 11 (p < 0.001, +2216 ± 236 au); 7 and 9 (p < 0.001, +2970 ± 302 au); 7 and 10 (p < 0.001, +2947 ± 324 au); 7 and 11 (p < 0.001, +2399 ± 242 au) (Figure 4.4 and Table 4.1).

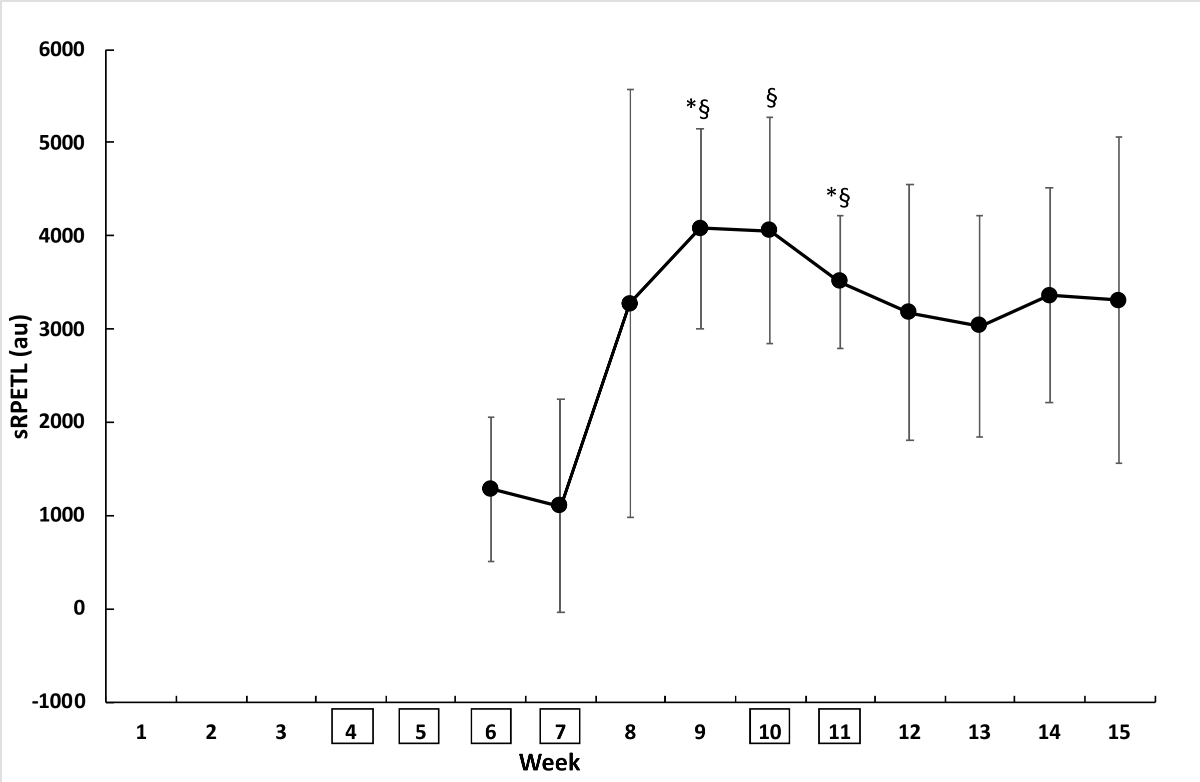


Figure 4.4: Mean (SD) changes in $sRPE_{TL}$ over the 15-week monitoring period

*Events in weeks: 4 – British rowing trials; 4 to 5 – university exam period; 5 to 7 – holiday; and 10 to 11 – 3-day training camp. * - p < 0.05 vs week 6; § - p < 0.05 vs week 7*

There was a significant main effect of time for volume load resistance training (F (7, 56) =18.391, p < 0.001, η_p^2 = 0.697) for available weeks (1 - 5 and 8 - 12) between weeks 1 and 5 (p < 0.023, -3389 ± 2416 au); 1 and 8 (p < 0.001, -10083 ± 2372 au); 1 and 9 (p < 0.001, +9845 ± 829 au); 2 and 5 (p < 0.001, -3389 ± 598 au); 2 and 8 (p < 0.001, +10247 ± 596 au); 2 and 9 (p = 0.001, +10009 ± 719 au); 3 and 5 (p < 0.001, -5439 ± 621 au); 3 and 8 (p < 0.001, +8033 ± 620 au); 4 and 5 (p < 0.001, +4205 ± 2283 au); 4 and 8 (p < 0.001, -9267 ± 2239 au); 4 and 9 (p = 0.002, +9029 ± 719 au) (Figure 4.5 and Table 4.1).

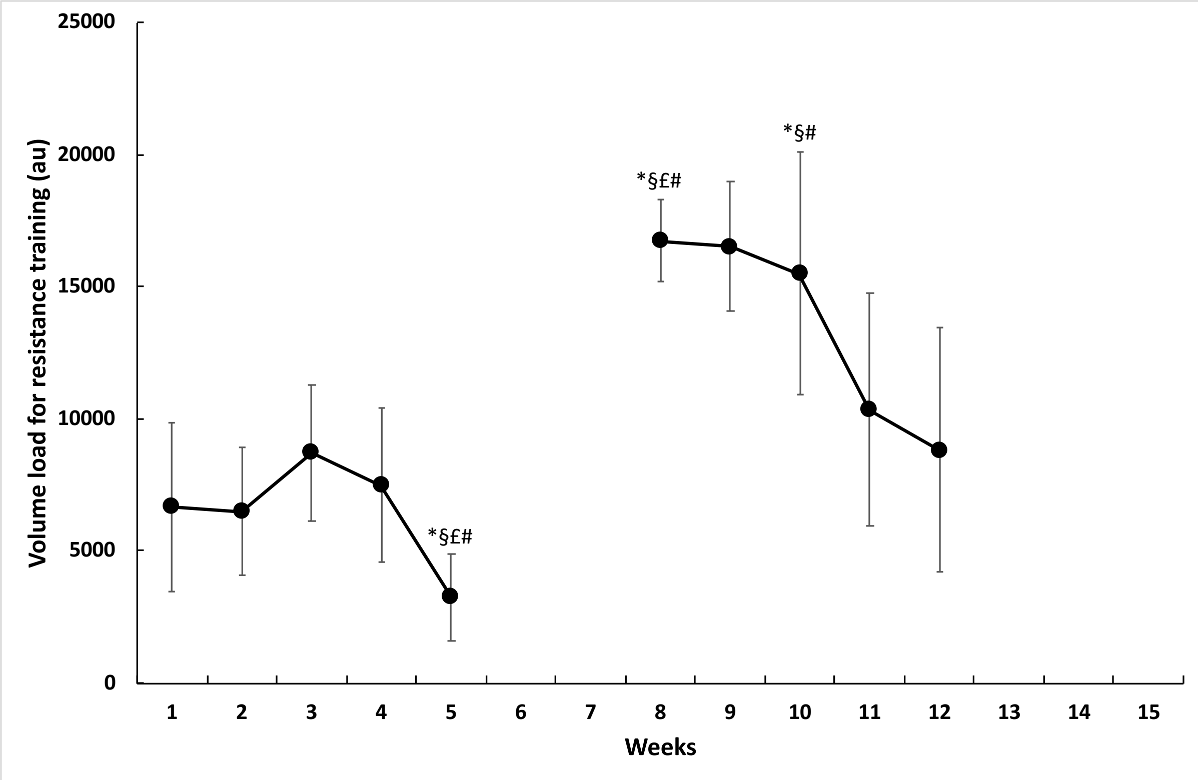


Figure 4.5: Mean (SD) changes in volume load for resistance training over the 12-week monitored period
*Events in weeks: 4 – British rowing trials; 4 to 5 – university exam period; 5 to 7 – holiday; and 10 to 11 – 3-day training camp. * - p < 0.05 vs week 1; § - p < 0.05 vs week 2; £ - p < 0.05 vs week 3; # - p < 0.05 vs week 3*

4.1.4. Rowing performance

There was no main effect of time for PO_{30} (F (10, 0) =1, p = 1, η_p^2 = 1) or PO_{2km} (F (2, 10) = 2.965, p = 0.097, η_p^2 = 1). Figure 4.6 indicates the variability in PO_{30} scores.

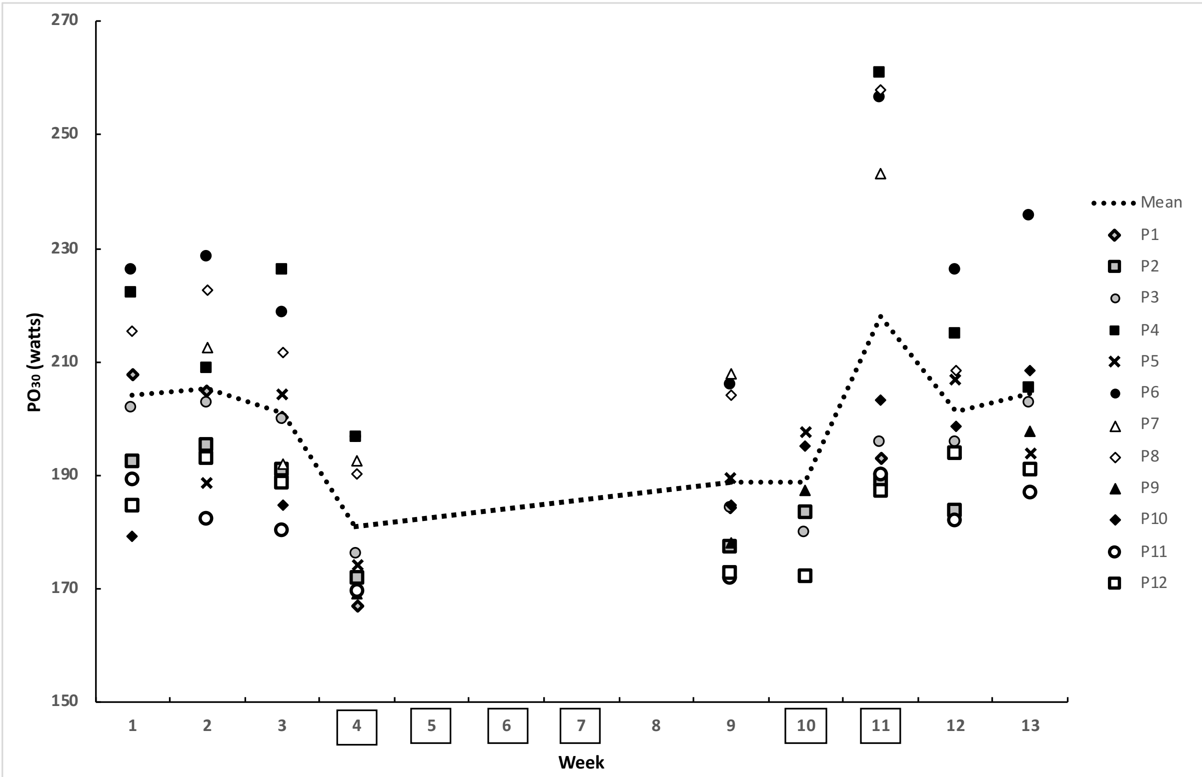


Figure 4.6: Changes in PO_{30} for each participant (i.e. P1 = participant 1) over the 15-week period

Events in weeks: 4 – British rowing trials; 4 to 5 – university exam period; 5 to 7 – holiday; and 10 to 11 – 3 day training camp. P – participant number.

4.2. Stress and Recovery scores

The main effect of time for stress and recovery constructs can be seen in Table 4.2. ARSS average stress and recovery scores are shown in Figure 4.7 where an opposing effect is clear although not significant: where stress goes up, recovery goes down; and vice-versa (r = -0.561, p = 0.058, 95 %CI: -0.889 – -0.164). It is clear that recovery increases (Holms Bonferroni significance between weeks unknown) during the holiday period as stress decreases (Holms Bonferroni significance between weeks unknown) from weeks 4 to 7 (-2.06 ± 1.21) and then stress returns to almost pre-holiday period stress score level – even though there is a drastic change in duration and training (Figure 4.7). The trend of stress is also increased, although not significantly, in the period before and during university exams (week 3-4) and decreased during the period of a 3 day training camp (week 10-11) and only increases again in week 13.

Table 4.2: Main effect of time determined for ARSS constructs

	Construct	Significance	Significant difference in weeks
Recovery	*Physical performance*	F (14, 98) = 1.108, *p* = 0.360, η_p^2 = 0.360	
	Mental performance	F (14, 98) = 1.548, *p* = 0.108, η_p^2 = 0.181	
	Emotional Balance	**F (14, 98) = 3.258, *p* < 0.001, η_p^2 = 0.318***	?
	Overall Recovery	**F (14, 98) = 3.471, *p* = 0.001, η_p^2 = 0.331***	?
Stress	*Muscle Stress*	**F (14, 98) = 3.364, *p* < 0.001, η_p^2 = 0.325***	1 and 8 (*p* < 0.001)
	Lack of Activation	F (14, 98) = 1.423, *p* = 0.157, η_p^2 = 0.169	
	Negative Emotional State	**F (14, 98) = 2.574, *p* < 0.001, η_p^2 = 0.328***	4 and 7 (*p* < 0.001) 7 and 15 (*p* < 0.001)
	Overall Stress	**F (14, 98) = 3.724, *p* < 0.001, η_p^2 = 0.327***	?

*Note: * - p < 0.05, ? – Holms Bonferroni pairwise comparison could not detect where the differences were due to the variance between participants*

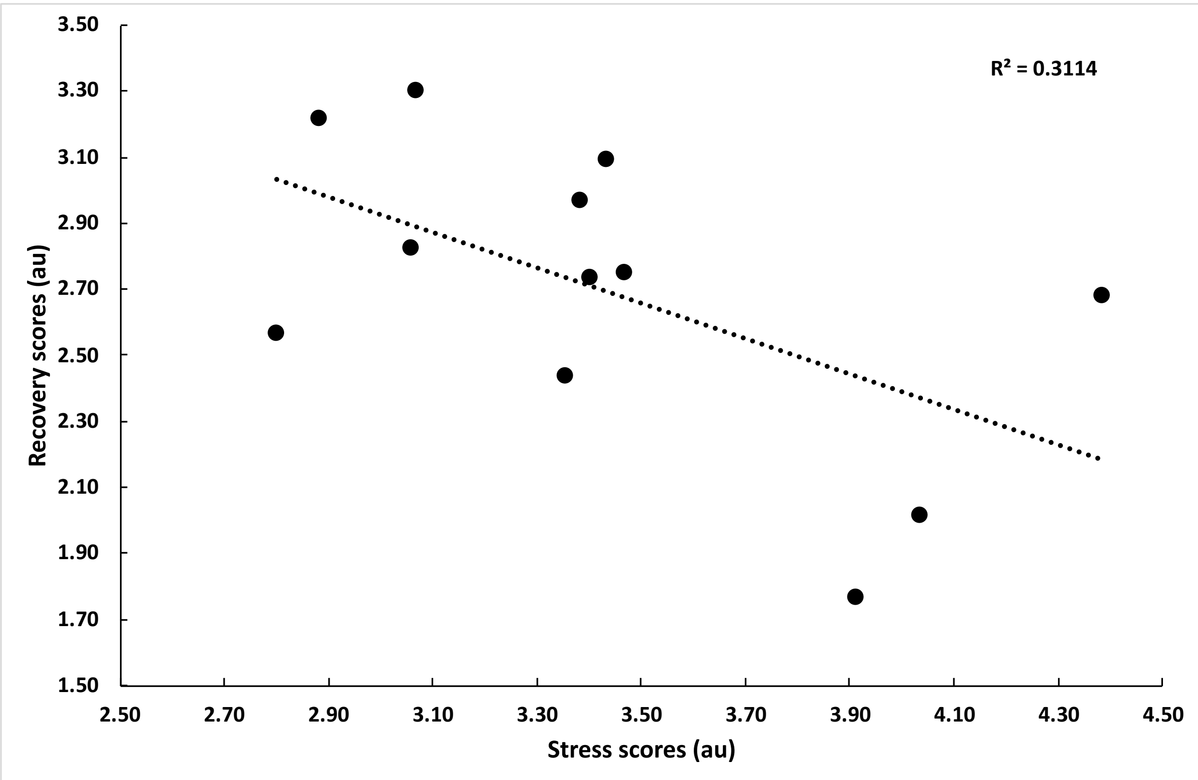


Figure 4.7: Relationship between ARSS Overall Stress and Overall Recovery construct scores for the mean 15-week period

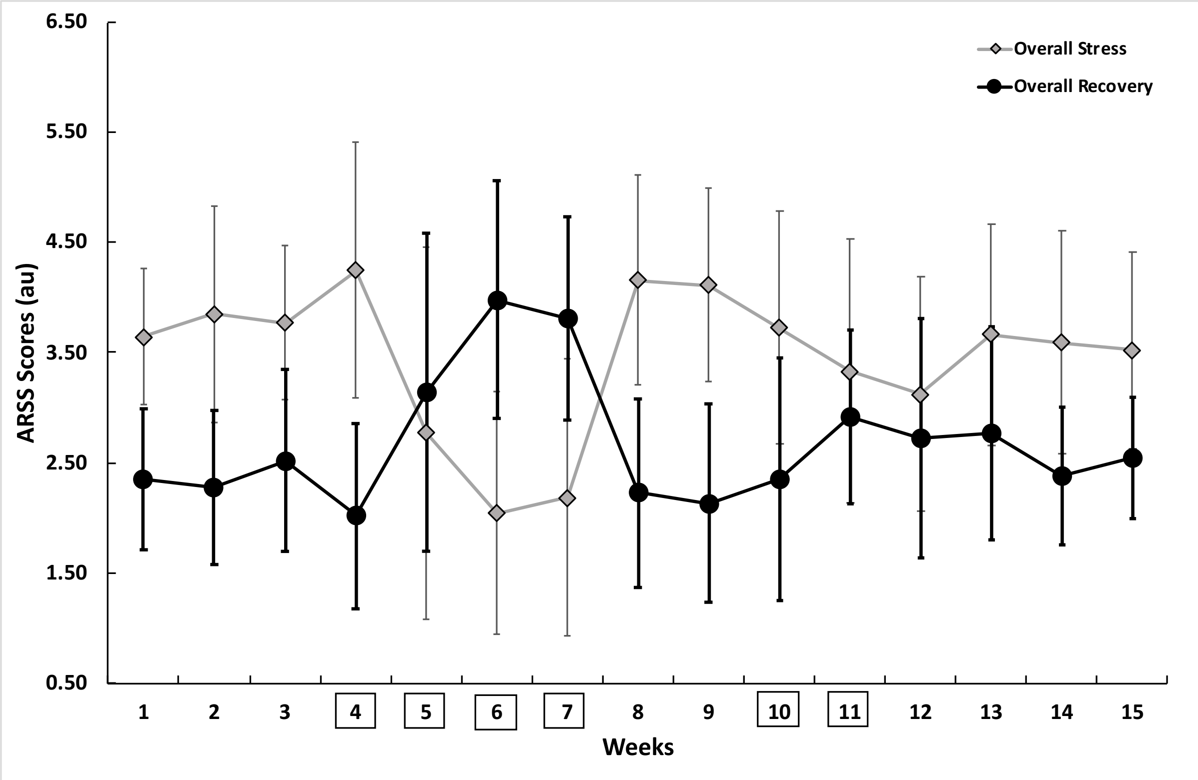


Figure 4.8: Mean (SD) changes in ARSS Overall Stress and Overall Recovery construct scores over the 15-week period

Events in weeks: 4 – British rowing trials; 4 to 5 – university exam period; 5 to 7 – holiday; and 10 to 11 – 3 day training camp.

For RESTQ-76 there were no significant main effect of time determined for any constructs (Table 4.3).

Table 4.3: RESTQ-76 main effect of time results

Specification	Construct	Main effect	Mean (SD) Scores
General stress	*General stress*	F (3, 30) = 0.524, P = 0.669, η_p^2 = 0.087	2.18 (1.04)
	Emotional stress	F (3, 30) = 0.756, P = 0.528, η_p^2 = 0.070	2.39 (0.97)
	Social stress	F (3, 30) = 0.517, P = 0.673, η_p^2 = 0.049	2.49 (0.96)
	Conflict/Pressure	F (3, 30) = 0.123, P = 0.946, η_p^2 = 0.012	3.48 (1.00)
	Fatigue	F (3, 30) = 0.506, P = 0.681, η_p^2 = 0.048	3.06 (1.05)
	Lack of energy	F (3, 30) = 0.936, P = 0.435, η_p^2 = 0.086	2.66 (0.77)
	Somatic complaints	F (3, 30) = 0.761, P = 0.525, η_p^2 = 0.071	2.61 (0.97)
General recovery	*Success*	F (3, 30) = 2.042, P = 0.129, η_p^2 = 0.170	2.71 (0.82)
	Social relaxation	F (3, 30) = 0.084, P = 0.968, η_p^2 = 0.008	3.88 (0.89)
	Somatic relaxation	F (3, 30) = 2.720, P = 0.062, η_p^2 = 0.214	2.49 (0.88)
	General well-being	F (3, 30) = 1.492, P = 0.237, η_p^2 = 0.130	3.40 (1.00)
	Sleep quality	F (3, 30) = 2.053, P = 0.128, η_p^2 = 0.170	2.79 (0.57)
Sport stress	*Disturbed breaks*	F (3, 30) = 0.211, P = 0.888, η_p^2 = 0.021	2.48 (0.95)
	Burnout/Emotional exhaustion	F (3, 30) = 0.821, P = 0.493, η_p^2 = 0.076	3.10 (1.13)
	Fitness/Injury	F (3, 30) = 0.418, P = 0.742, η_p^2 = 0.040	4.03 (0.87)
Sport recovery	*Fitness/Being in shape*	F (3, 30) = 2.012, P = 0.133, η_p^2 = 0.167	2.38 (0.92)
	Burnout/Personal Accomplishment	F (3, 30) = 1.921, P = 0.147, η_p^2 = 0.161	3.10 (0.98)
	Self-efficacy	F (3, 30) = 0.783, P = 0.513, η_p^2 = 0.073	2.56 (0.98)
	Self-regulation	F (3, 30) = 1.138, P = 0.350, η_p^2 = 0.102	3.60 (1.00)

Notes: Mean (SD) scores are the mean and SD over the whole period.

4.3. Relationships with training load

4.3.1. Relationships between training load measures

As seen in Table 4.4, moderate significant relationships were determined between internal training load (i.e. HR_{TL} and $sRPE_{TL}$) variables and external distance measured. No other significant relationships were determined between variables.

Table 4.4: Relationships between external and internal training load variables

	HR_{TL} (au)	**$sRPE_{TL}$ (au)**
Distance (km)	***r* = 0.591 (0.084 - 0.908)***	***r* = 0.646 (0.129 - 0.952)***
Distance + $VL_{resistance}$ (au)		*r* = 0.162 (-0.332 - 0.672)
$sRPE_{TL}$ (au)	*r* = 0.581 (0.157 - 0.869)	

*Note: $VL_{resistance}$ – volume load for resistance training, au – arbitrary units. * - $p < 0.05$*

4.3.2. Relationships between training load measures and performance

A moderate significant relationship was determined between HR_{TL} and mean difference between the PO_{30} in week 0 and each participant's best score achieved over the 15 week period (*p* = 0.037, *r* = 0.606, 95 %CI: 0.174 – 0.863) (Figure 4.8). No significant relationships were determined between mean difference in PO_{30} (best minus baseline) and $sRPE_{TL}$ (*p* = 0.488, *r* = 0.234, 95 %CI: -0.335 – 0.726), mean difference in PO_{2km} (best minus baseline) and HR_{TL} (*p* = 0.740, *r* = 0.113, 95 %CI: -0.526 – 0.847), and mean difference in PO_{2km} and $sRPE_{TL}$ (*p* = 0.717, *r* = 0.131, 95 %CI: -0.356 – 0.534).

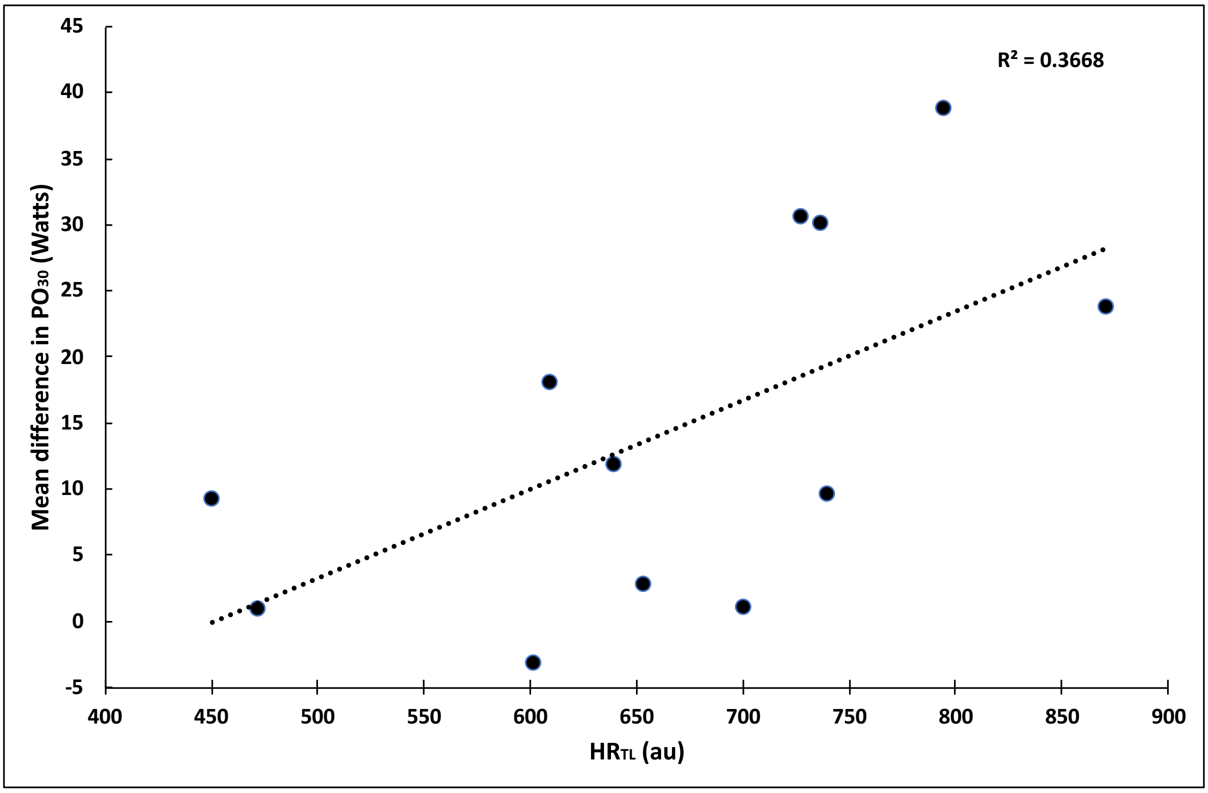


Figure 4.9: Relationship between HR_{TL} and mean difference in 30 min performance

Events in weeks: 4 – British rowing trials; 4 to 5 – university exam period; 5 to 7 – holiday; and 10 to 11 – 3 day training camp

4.3.3. Relationships between training load and stress and recovery constructs

Due to the lack of significance, the RESTQ-76 will not be used in analysis with training loads. As seen in Table 4.5, there is a strong relationship between $sRPE_{TL}$ and *Physical Performance capacity* (*p* = 0.004) recovery construct from the ARSS questionnaire. No other relationships were determined between internal and external training load measures and the ARSS questionnaire constructs. Figure 4.10 depicts the strong relationship between $sRPE_{TL}$ and *Physical Performance capacity*.

Table 4.5: Correlation relationships and 95% confidence intervals (range) between training load variables and ARSS constructs

	Recovery				Stress			
	Physical performance	**Mental performance capacity**	**Emotional balance**	**Overall Recovery**	**Muscle stress**	**Lack of activation**	**Negative emotional state**	**Overall Stress**
HR_{TL} (au)	*r* = 0.567 (0.194 – 0.817)	*r* = 0.532 (0.061 – 0.865)	*r* = 0.258 (-0.144 – 0.602)	*r* = 0.298 (-0.150 – 0.727)	*r* = -0.283 (-0.573 – -0.042)	*r* = -0.078 (-0.482 – 0.631)	*r* = 0.100 (-0.448 – 0.592)	*r* = -0.133 (-0.429 – 0.121)
$sRPE_{TL}$ (au)	***r* = 0.784* (0.378 – 0.967)**	*r* = 0.370 (-0.076 – 0.671)	*r* = 0.164 (-0.551 – 0.605)	*r* = 0.203 (-0.434 – 0.748)	*r* = 0.404 (-0.358 – 0.867)	*r* = -0.352 (-0.858 – 0.791)	*r* = 0.166 (-0.566 – 0.858)	*r* = 0.116 (-0.515 – 0.723)
Distance (km)	*r* = 0.534 (-0.219 – 0.863)	*r* = 0.483 (0.018 – 0.787)	*r* = 0.410 (-0.030 – 0.764)	*r* = 0.293 (-0.029 – 0.635)	*r* = 0.110 (-0.319 – 0.569)	*r* = 0.105 (-0.582 – 0.881)	*r* = -0.221 (-0.753 – 0.489)	*r* = 0.097 (-0.409 – 0.498)
Distance + $VL_{resistance}$ (au)	*r* = 0.265 (-0.213 – 0.763)	*r* = 0.149 (-0.343 – 0.495)	*r* = 0.173 (-0.303 – 0.509)	*r* = 0.127 (-0.373 – 0.656)	*r* = 0.124 (-0.551 – 0.707)	*r* = -0.184 (-0.546 – 0.196)	*r* = -0.359 (-0.778 – 0.418)	*r* = -0.186 (-0.687 – 0.314)

*Note: presented as R-value (95%CI), * - p < 0.05. $VL_{resistance}$ – volume load for resistance training, au – arbitrary units.*

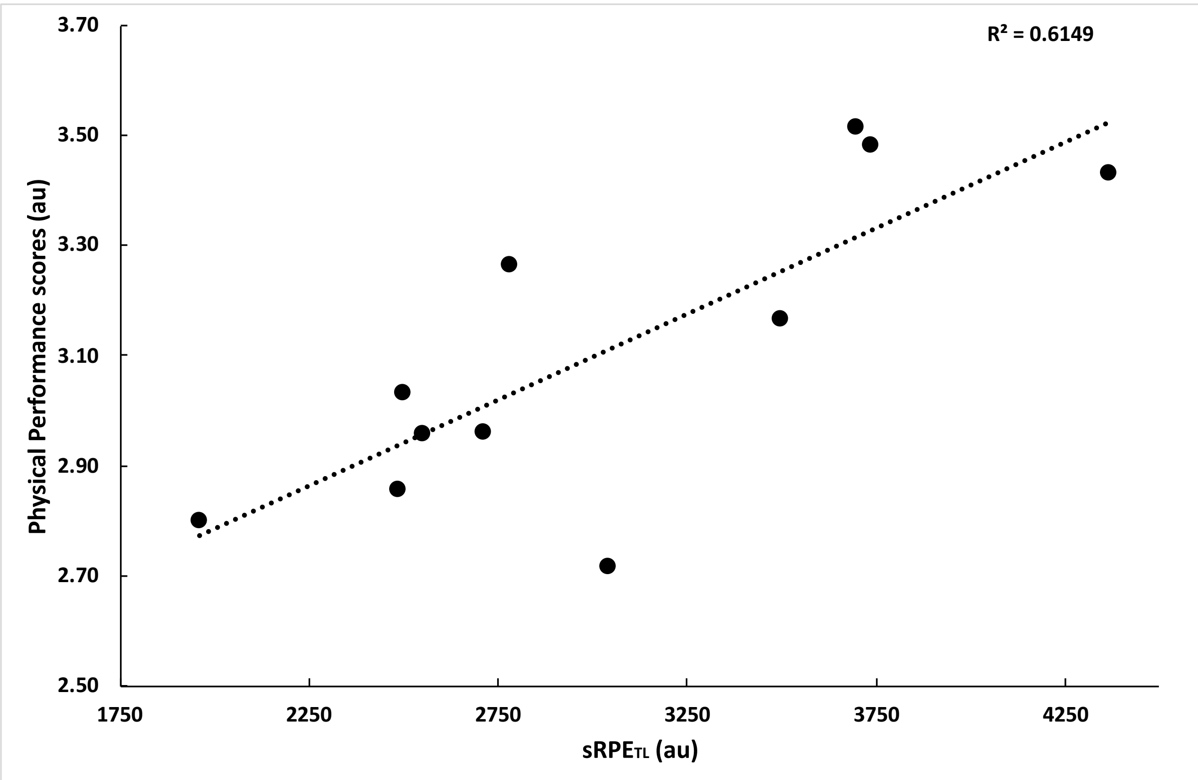


Figure 4.10: Relationship between $sRPE_{TL}$ and Physical Performance scores from the ARSS.

4.4. Burnout

There was no significant difference over time for *Reduced sense of accomplishment* (p = 0.262, d = 0.733); *Emotional/Physical exhaustion* (p = 0.099, d = 0.309); and *Devaluation of sport* (p = 0.485, d = 0.874) (Figure 4.10).

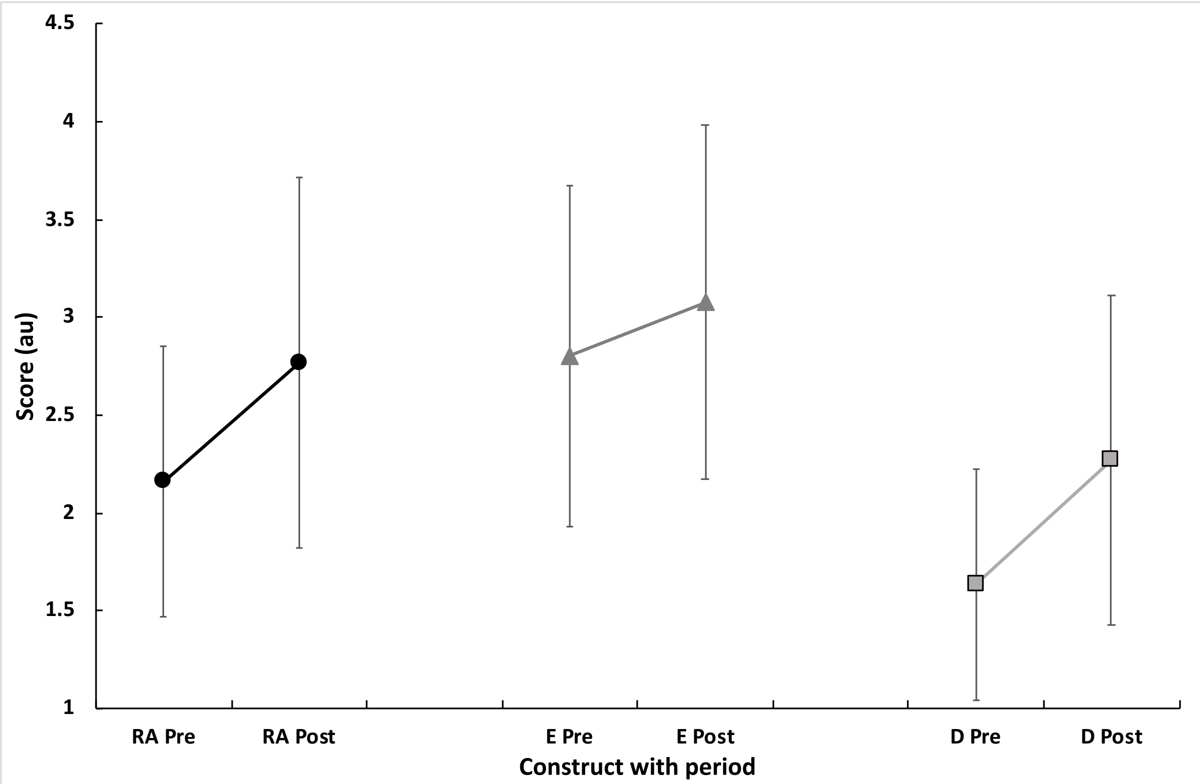


Figure 4.11: ABQ constructs pre and post 15-week monitoring period

Note: Pre – week 1; and Post – week 14. RA – Reduced sense of accomplishment; E – Emotional/Physical exhaustion; D – Devaluation; Group-1 – higher trainers than mean HR_{TL} ; Group-2 – lower trainers than mean HR_{TL}

4.5. Academic stress

There was a significant main effect of time for *Time Restraint* (F (14, 98) = 2.461, p = 0.005, η_p^2 = 0.260) but the Holms Bonferroni pairwise comparison could not detect where any differences existed between weeks due to a small sample size and a large variance in responses from participants (Figure 4.12). However, no significant main effect of time was determined for *Perception of workload* (F (14, 98) = 1.538, p = 0.112, η_p^2 = 0.180). The university exam period (weeks 4 – 5) did not affect either constructs for academic stress.

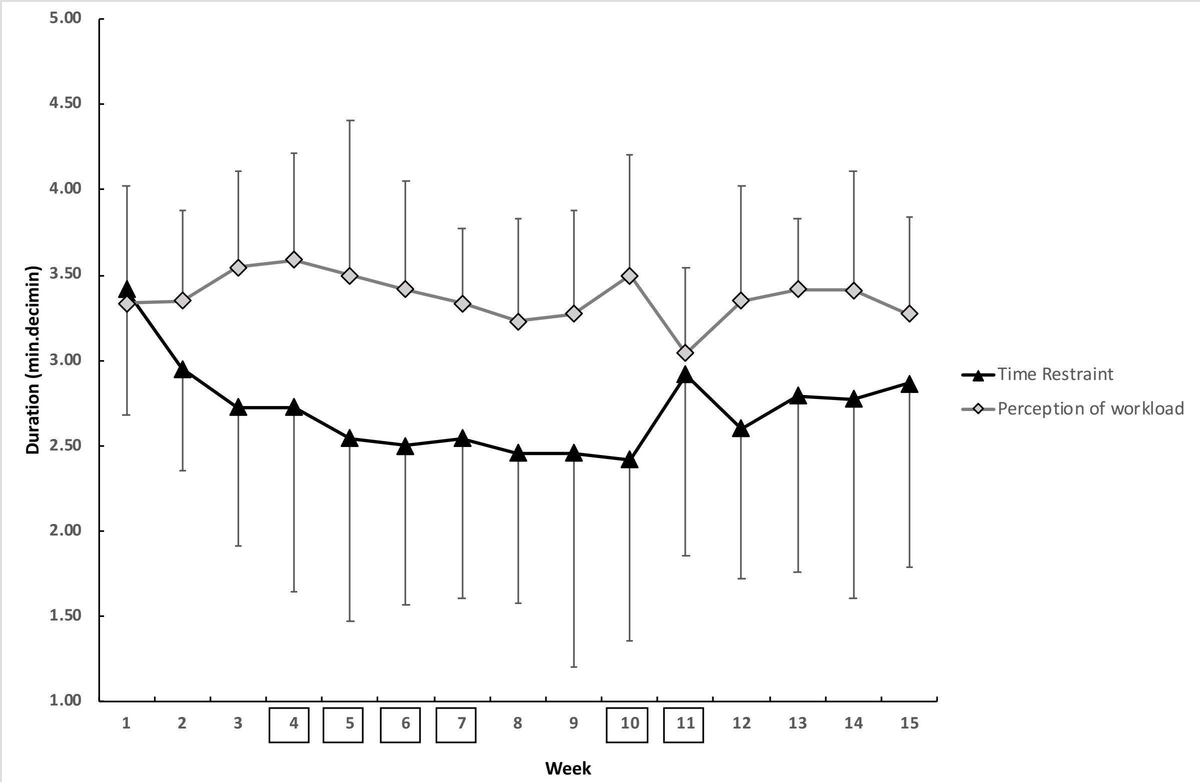


Figure 4.12: Changes in Academic stress over the 15-weeks

*Events in weeks: 4 – British rowing trials; 4 to 5 – university exam period; 5 to 7 – holiday; and 10 to 11 – 3 day training camp. * - p < 0.05 with week 1 Time Restraint.*

4.6. Post study exit interviews in week 28 of longitudinal study

Of the 11 participants who completed the post study exit interviews, participants were 93 ± 5 % compliant with filling in the ARSS questionnaires and estimated that 92 ± 6 % of all sessions completed were uploaded to their Polar Flow account. Participants also estimated that they were 71 ± 21 % and 89 ± 10 % honest on the RPE information sheets (due to recall) and ARSS questionnaire (respectively). See summary in Appendix 11.4.

5. Discussion

Therefore, the aims of this investigation are to: i) describe the training practices of UK female student rowers; ii) determine the relationships between different measures of internal load and external training load;; iii) determine the relationships between different measures of internal training load and responses to recovery-stress questionnaires; and iv) determine the relationships between training load and rowing performance. Based on evidence from Collette *et al.* (2018) who reported a relationship between $sRPE_{TL}$ and daily ARSS in five female swimmers, it was hypothesised that there will be a relationship between the ARSS constructs and training load measures (especially $sRPE_{TL}$). However, the hypothesis that a relationship will be established between the ARSS constructs and training load measures was rejected due to no significant relationships found between the majority of the ARSS constructs and training load measures, with the exception of $sRPE_{TL}$ and *Physical Performance capacity*.

5.1. Description of training practices of female collegiate rowers

5.1.1. Description of training

Over 11 of the 15-weeks, an average of 11 ± 3 sessions·wk^{-1} were completed with 2 ± 1 sessions·wk^{-1} on the ergometers; 5 ± 2 sessions·wk^{-1} rowing on the water; 2 ± 1 sessions·wk^{-1} resistance training; and 2 ± 1 sessions·wk^{-1} doing '*Other*' training. The majority of the rowers training consisted of rowing specific training (62 ± 16 %; on water rowing 44 ± 11 %, and ergometer 18 ± 5 %) with the remaining consisting of resistance training (22 ± 5 %) and other training (e.g. cycling, running, and swimming; 16 ± 13 %) (Figure 4.1). This distribution is similar to the results Guellich *et al.* (2009) observed in 36 German male junior national rowers (19.2 ± 1.4 y) over a 37-week training season i.e. rowing specific (52 %); resistance training (23 %); other (e.g. jogging, general athletic training) (17 %); and warmups (8 %). Within the current study the warmup periods were included within the training times and could therefore alter the results slightly if it were kept separately. During the holiday period (weeks 6 - 7) this distribution in mode of training differed with athletes completed a relatively greater percentage of time doing '*Other*' training (39 ± 7 %). This could be due to the athletes not having access to rowing boats; a stretch of water; and an ergometer or that they prefer to do these types of training when they get the choice. There were no main effects of time (p > 0.05) observed over the 15-week period for any mode of training.

Weekly training hours significantly differed between weeks that fell within the preparation phase (8.1 ± 2.2 h·wk^{-1}); Christmas holiday (4.7 ± 2.6 h·wk^{-1}); and pre-competition phase (10.9 ± 2.4 h·wk^{-1}) (see Table 4.1). Overall, the average weekly training hours of the rowers were lower than that observed in 21 Australian elite rowers (7-female and 14-male) where a median of 19.4 h·wk^{-1} (range 3.2 - 21.9 h·wk^{-1}) and 18.9 h·wk^{-1} (range 16.2 - 22.1 h·wk^{-1}) was observed in the specific preparation phase; and 17.6 h·wk^{-1} (8.7 - 21.1 h·wk^{-1}) and 19.1 h·wk^{-1} (range 1.9 - 24.0 h·wk^{-1}) during the competition phase, respectively (Tran *et al.* 2015). The disparity between the two cohorts could be explained by the rowers in the current study being well-trained and not competing at the elite level. In addition, British Rowing recommend that Level 4 rowers (i.e. '*Competitive club rowers and those breaking into high performance*') over the age of 17 years old to complete a training load of 6 - 12h·wk^{-1} and number of weekly sessions to average 6 with a maximum of 8; training loads similar to the cohort examined in this study.

5.1.2. Description of HR training intensity distribution

The HR training intensity distribution of the rowers was 51 ± 4 % of training at an intensity below LT1 with remaining above LT1 (49 ± 4 %). This distribution does not correspond to the 'optimal' polarised training intensity distribution of 80 % <LT1 and 20 % >LT1 approach observed by Seiler (2010) in elite and sub-elite endurance athletes. In a review of training practices of well-trained and elite endurance athletes, Stöggl and Sperlich (2015) found that from 1970 to 2014, the training intensity distribution varied between ~70 % to 95 % duration of training <LT1 for sub-elite and elite rowers. The difference in HR training intensity distribution between the populations investigated in Seiler, (2010) and Stöggl and Sperlich (2015) and the rowers in the current study could be due to the athletes in the current study competing at a lower level and are dual career athletes (i.e. student-athletes) and therefore may require different distributions of training intensity than that of athletes who are likely to either have higher training loads and/or a greater training background; a philosophy that is adopted by the coach who

prescribed the training which may also explain this difference. The training intensity distribution <LT1 from preparation phase (weeks 1 - 5; 50 ± 4 %) to pre-competition phase (weeks 8 - 11; 53 ± 3 %) is considerably smaller than that observed by Guellich *et al.* (2009) in the basic preparation phase (96 %) below 2 mmol.L^{-1} and in competition phase (94 %). A reduction in training intensity distribution <LT1 is not observed in the current study which could be explained by the fact that a competition phase was not monitored in this project and therefore a direct comparison cannot be made.

The training intensity distribution in the current study does not represent the training intensity distribution of a 3-zone model (due to a lack of LT2 being determined in some participants) which would indicate percentage of training spent in differing zones-2 and 3 (i.e. splitting the current zone-2 [training intensity distribution >LT1] into zone-2 [training between LT1 and LT2] and zone-3 [training >LT2]). Splitting zone-2 would make it possible to determine whether the cohort are completing more training in zone-3 which has been shown to lead to signs of overreaching and overtraining (Esteve-Lanao *et al.*, 2007) and therefore as one of the many causes of injury and illness could consequently lead to an increase in the rate of injury and illness. The pilot study by Esteve-Lanao *et al.* (2007) reported that when twenty sub-elite male endurance 5 km runners (regional to national level) trained greater than 15 % training time in zone-3 the athletes showed signs of overreaching and overtraining. In the study, they indicated that no athletes got injured during the 5-month period. If zone-2 was divided it would be possible to determine whether the injuries experienced by the rowers (not included in study) were due to more time spent in zone-3. Within the study Esteve-Lanao *et al.* (2007) also indicated that well-trained endurance athletes spending more time in zone-2 (>20 %) rather than zone-1 may experience impaired competitive performance. This could possibly indicate why there was little to no performance increase ($p > 0.05$) in the PO_{2km} in the current study as ~49 % of the training was spent in zone-2 (however it is unknown whether the majority is in zone-2 or zone-3).

There is a limitation in making comparisons between the training intensity distribution observed in relevant studies due to the variation in how training *'zone 1'* is defined. In the review by Stöggl and Sperlich (2015), the authors from multiple investigations cited different ranges as a threshold for '*Zone-1*' for rowers; these include training at lactate levels below (with the corresponding percentages of duration in '*Zone-1*') LT1 (77.3 %); 1.5 mmol·L^{-1} (75 %); 2 mmol·L^{-1} (70-94 % depending on phase); 2.5 mmol·L^{-1} (~68 %); and 4 mmol·L^{-1} (95 %). With such a vast range of defined '*Zone-1*', the 'optimal' intensity is vague (i.e. <LT1 or at 4 mmol·L^{-1}) and can be misleading in the comparison to the absolute individual LT1 of athletes. However, the 'optimal' training intensity distribution suggested by Seiler (2010) has been based on observations of successful elite endurance athletes but is not intervention evidence based.

5.2. Relationship between internal and external training load

A main finding of the current study is that both subjective $sRPE_{TL}$ (r = 0.646) and objective HR_{TL} (r = 0.591) have a moderate relationship with external training load (i.e. distance) on a group level. This finding indicates that both measures are sensitive to detecting changes in training load, but due to the small shared variance between training load measures (i.e. $sRPE_{TL}$: R^2 = 0.417; and HR_{TL}: R^2 = 0.349) and distance, the ability of the training load measures to accurately reflect changes in the internal physiological and psychological stress of the rowers to the external stress of training may be limited. Therefore, other physiological or psychological measures may be more suitable or need to be combined with the training load measures under investigation to improve their accuracy. The results of this investigation also suggest that the internal training load measures are not interchangeable with each other due to the different arbitrary units and no significant relationship being determined between them (Foster *et al.*, 2001).

5.2.1. Quantifying training with HR_{TL}

Many HR-based methods are used to quantify training intensity e.g. HR recovery, HR reserve, HR during exercise and HR TRIMP (Buchheit, 2014). These methods have been determined as reliable with aerobic and anaerobic steady-state training but should be combined with other measures (i.e. psychology; training logs; and performance tests) to inform coaches and practitioners on wellness, performance and fatigue of the athletes (Buchheit, 2014). In the current study we could not use an individualised TRIMP method for training load because were unable to determine an anaerobic threshold (LT2) for three athletes. These athletes did not attain high enough wattages in the last two stages of the incremental step test (i.e. correlating to a B_{LA} higher than 4 mmol·L^{-1}) because of the information provided by the coach for the athletes not correlating with their current fitness level and/or a time limit taking away the ability to do a maximal all-out 7th stage as rowers were tested in big groups so that other training for the day was not undermined. We therefore used %HR_{max} as a lactate threshold concept (i.e. lactate threshold points used to predict training zones; Faude *et al.,* 2009) presented by Bourdon (cited in Tanner and Gore, 2013) to determine a TRIMP method to use for measuring training load. However, arbitrary %HR_{max} limits the true value of individuality of HR responses for athletes as individual thresholds at %HR_{max} may not correlate with the arbitrary zones and using a weighting factor that is arbitrary may over- and/or underestimate the actual response to training. The method is similar to Edward's TRIMP with percentages of HR_{max} for the 5-intensity zones with a factor of multiplication in each zone (Appendix 11.2, equation 6). Edward's TRIMP was not implemented within the study due to the intensity-zones HR_{max} percentages being viewed as too far from the HR_{max} percentages associated with individual lactate thresholds of athletes. Whereas, the percentages represented by Bourdon is more specific to endurance athletes as it was based on thousands of incremental endurance tests on athletes in Australia and akin to the HR_{max} percentages associated with the lactate thresholds measured within the cohort of the current study. The difference in percentages can be seen in (Appendix 11.1a). The HR_{TL} method of the current study has not been considered nor validated within research, so making comparisons with other HR-based TRIMP methods is misleading. Although, interestingly Dellavalle and Haas (2013) used an altered summated HR method (i.e. zone1 – <55; zone2 – 55-64; zone3 – 65-74; zone4 – 75-84; zone5 – 85-94; and zone6 – >95 %HR_{max}) so that HR zones better reflected the rowers of the studies intermittent and diverse training patterns. This method has also not been validated to determine training load.

5.2.2. Quantifying training with $sRPE_{TL}$

$sRPE_{TL}$ has been quantified in many modes and different types of training – which is a very important factor for this study. The athletes within the current study completed training of different intensities (i.e. below LT1, above LT1, and high-intensity interval training); modes (rowing ergometer; cycling ergometer; boat on water; running; cycling; and swimming) and types (i.e. aerobic; anaerobic; and resistance). $sRPE_{TL}$ was determined as a sensitive tracker of external training (i.e. distance) on a group level.

There was a spike observed in week-8 (return from holiday period) in $sRPE_{TL}$ and training volume in comparison to weeks 6-7 (but did not reach statistical significance). The elevated $sRPE_{TL}$ is sustained for weeks 9-10 (significantly difference of $p < 0.05$ to week-7) and reduced slightly in week-11 (Table 4.1). This is similar to the trend of the training volume that is significantly different ($p < 0.05$) in weeks 9-10 from week-7. This indicates the sensitivity of the total $sRPE_{TL}$ method to changes in external training load.

Similarly, Dellavalle and Haas (2013) determined a significant relationship ($p = 0.005$) between training volume and $sRPE_{TL}$ method for 7 American collegiate female rowers (19.7 ± 0.9 y; 73.7 ± 10.5 kg; 22.8 ± 4.1 % body fat). The study was conducted by 3 lab tests (i.e. 1x a maximum aerobic power test to establish VO_{2peak}; and 2 x ergometer workouts to simulate an easy and hard on-water training session), and one week of on-water training monitoring (64 total training sessions; i.e. steady-state and drills, endurance, strength and power, and mixed training) from HR responses (for HR summation -TRIMP) and visual analogue scale RPE. Although the RPE scale used was different, the results indicate that for athletes in the current study both training load methods (HR_{TL} and $sRPE_{TL}$) are applicable. Similar results were found for the same $sRPE_{TL}$ method (Foster *et al.*, 2001) as used within the current study in rowing (Tran *et al.*, 2015a), football (Impellizzeri *et al.*, 2004), Australian football (Scott *et al.*, 2013), strength and conditioning training (Day *et al.*, 2004), cycling and basketball (Foster *et al.*, 2001).

In the post-study exit interviews (week-29) the participants estimated that 72 ± 21 % (range 20 - 100 %) of the RPE sheet results were accurate. This is a very wide range of inaccuracy estimates stated by the participants due to problems with recall. Participants highlighted that they generally provided RPE scores for sessions on either i) the same day ($n = 4$); ii) after 24 – 48 h ($n = 4$); up to a week after ($n = 1$); and iv) longer than a week after ($n = 3$). This questions the accuracy of the $sRPE_{TL}$ results presented in the current study as sRPE scores could be under or overestimated which influencing the accuracy of the relationships determined. Foster *et al.* (2001) found that individual athletes answer the RPE per session very consistently within their own pattern of using the RPE scale. Therefore, if memory recall of RPE was reduced in this cohort, better relationships could have been established between $sRPE_{TL}$ and ARSS, and combined objective measures of training load. RPE is seen as a psychophysiological integrator, which considers not just the physiological but also the psychological strain that the athletes experience (Eston, 2012) making it a useful tool to monitor training if accurate measures are taken.

5.2.3. Relationships between internal and external training loads

There was a statistically significant moderate relationship determined between mean HR_{TL} and distance (r = 0.591), which indicates that the HR-TRIMP method is moderately sensitive to changes in external training load. Similarly, there was a statistically significant moderate relationship determined between total $sRPE_{TL}$ and distance, which indicates that the training load method is also moderately sensitive to changes in external training load but caution should be taken as the $sRPE_{TL}$ calculation of internal load included both the aerobic based sessions and strength and conditioning sessions. Therefore, $sRPE_{TL}$ was also assessed with combined distance and volume load for resistance training to determine whether there was an overall relationship, but no significant relationship was determined. Indicating that when looking at all the training together $sRPE_{TL}$ is not sensitive enough to track training load. The relationship may change with distance if the $sRPE_{TL}$ of the same sessions were correlated instead. However, no relationships were established between HR_{TL} and $sRPE_{TL}$. One plausible reason for this finding maybe because $sRPE_{TL}$ was calculated from all types of training sessions (i.e. resistance training; aerobic; and anaerobic) whereas the internal load determined by HR_{TL} is only for the aerobic training or steady state training and volume load of resistance training is the external load for strength and conditioning sessions only. However, a relationship between $sRPE_{TL}$ and the external load that was calculated using both distance and volume load of resistance training was also not established. This may be due to the possible inaccuracy of the $sRPE_{TL}$ measures (i.e. based on recall for majority of athletes) the actual training load could be over-/underestimated hindering the relationship potential. This possible inaccuracy may explain why the two internal measures are not associated with each other as found in previous research.

Dellavalle and Haas (2013), established a very strong significant correlation (r = 0.88, p < 0.001) between the $sRPE_{TL}$ and HR summation method of calculating internal training load for 64-training sessions (as discussed in section 5.2.2). Similarly, researchers such as Impellizzeri *et al.* (2004); Scott *et al.* (2013); Tran *et al.* (2015a) have also determined significant correlations between HR-TRIMP methods (i.e. Edward's, Banister's TRIMP, and T2minute method respectively) and $sRPE_{TL}$ in football, Australian football, and rowers, respectively. This could, again, be due to the $sRPE_{TL}$ in the current study encompassing all the different trainings where in the studies mentioned the $sRPE_{TL}$ is for the same training sessions as the HR-TRIMP methods. This indicates to the difficulty of in-field measuring of all data and the comparability between methods. Although not investigated within the current study, research by Borresen and Lambert (2009) has determined that HR-TRIMP methods (i.e. Banister's TRIMP; Lucia's TRIMP; Edward's TRIMP) may overestimate training load when a higher percentage of training is at high-intensities often and underestimate training load when a higher percentage of training is at low-intensities. They stated that it could be due to HR-TRIMP having 5-intensity zones that could place an athlete in a higher/lower intensity with just a change of 1 bpm. Alternatively, they indicated that $sRPE_{TL}$ could be underestimating training load at high-intensities and overestimating at low-intensities. This could possibly have occurred in the current study and would need further investigation as Sanders *et al.* (2017) found in 15 well-trained male cyclists for a 10-week pre-season period that RPE was underestimated when the cyclists were doing low-intensity training (zone-1 HR training intensity distribution) and overestimated when time was spent in zone-2 and 3 (HR training intensity distribution) compared to objective measures of HR and PO (all in 3-zone model).

As previously stated, no relationship was established between volume load for resistance training and HR_{TL}. This is comparable to other research as the HR-TRIMPs have an inability to quantify non-aerobic exercise (i.e. such as resistance training) due to the increase in HR being disproportionate to the demand on the athletes' body (Borresen and Lambert, 2009). In the review on the quantification of training load and performance, the researchers indicate that HR responses do not match the demands placed on individuals' bodies during resistance exercise leading to RPE being used as a method to quantify training load in strength and conditioning (Borresen and Lambert, 2009). Impellizzeri *et al.* (2004), confirms that there is a lower accuracy for HR monitoring to determine the demand of high-intensity and intermittent training.

5.2.4. Relationships between internal and external training loads summary

Therefore, HR_{TL} is sensitive enough to determine the acute changes in training over time (i.e. distance), but caution should be taken as the volume of missing data hinders the accuracy of the HR_{TL}. Similarly, total $sRPE_{TL}$ is sensitive enough to track the changes in aerobic and steady-state training (i.e. distance) for this group but has not been able to track changes of total training variables (i.e. combined measures). This indicates that the $sRPE_{TL}$ is not a sensitive measure in assessing changes in training load in the population at a group level investigated in the current study.

5.3. Relationship between training load and performance

Maximal power test (2 km ergometer test) are commonly used to determine the ability of the rowers to complete a 2 km on-water race and also to track performance changes throughout the season. The 2 km ergometer race also gets used as seat race to determine the rowers' position within the boat. This indicates that the 2 km testing is assumed to be predictive of 2 km on-water performance. This is in accordance with the weak-moderate relationships found Mikulić *et al.* (2009) (i.e. smaller boats: r = 0.64 – 0.92, $p \leq 0.025$; larger boats: r = 0.31 – 0.70, $p \leq 0.039$). Opposingly, McNeely (2012) found no relationship between 2 km on-water rowing and 2 km ergometer rowing. The conclusion from McNeely (2012) is more in accordance with the weak to moderate relationships found in Mikulić *et al.* (2009), as the relationships determined do not provide a high chance of the athlete being able to perform well on water if they perform well on the ergometer. The conclusion from Mikulić *et al.* (2009) should be revised as the strength of the correlations (shared variance of: small boat 41 – 85 % and larger boats 10 – 49 %) are not high enough to provide sufficient evidence to conclude that the 2 km ergometer test is an effective method to predict on water 2 km performance, this is especially true in larger boat athletes. Questioning the use of the 2 km ergometer rowing testing for prediction of performance and selection of seat positions. There were no significant relationships determined between the internal training load measures and differences in PO_{2km}.

Capostagno *et al.* (2019) determined that using the Lambert and Lambert submaximal cycle test that stage 2 (6 min @ 80 $\%HR_{max}$) was sensitive enough to track changes in training status and progressions (i.e. adaptations and improvements) of cyclists. Within the study 15-male cyclists (aged 21 - 45 years) participated in completing a pre-testing (40 km time trial and PO_{peak} test 2 days later); 2-weeks high-intensity interval training (HIIT; 4 supervised HIIT [20 x 1 min @PO_{peak} with 2 min active recovery @50 W] and Lambert and Lambert submaximal cycle tests [3-stage: stage-1 – 6 min @60 $\%HR_{max}$; stage-2 – 6 min @80 $\%HR_{max}$; and stage-3 – 3 min @90 $\%HR_{max}$]); and post-testing (40 km time trial and PO_{peak} test 2 days later) to determine the variables which best predict positive responses to training. The participants were divided into two groups based on improving or no improvement on the 40 km time trial (adaptors and non-adaptors; respectively). When comparing the 3-stages of the Lambert and Lambert submaximal cycle tests and $\%HR_{max}$ that represent lactate thresholds (Table 3.2), it is observed that stage-1 corresponds to <LT1; stage-2 – ±LT2; and stage-3 – >LT2. Therefore, stage-2 represents anaerobic threshold which is similar to 30min performance tests in rowing. This explains why submaximal 30 min all-out rowing tests are used by coaches and practitioners to test the development of rowers' aerobic power and to monitor response to training (i.e. continued decrease in performance could indicate that an athlete is becoming overtrained and possibly in danger of non-functional overreaching) (Smith *et al.*, 2011).

Mean difference of PO_{30} had no relationship with mean $sRPE_{TL}$ and had a significant moderate relationship with average HR_{TL} (r = 0.606, p = 0.037, 95 %CI: 0.174 – 0.863) indicating that average HR_{TL} compared to $sRPE_{TL}$ is more sensitive to the dose-response to training of the group and therefore may possibly be a better method to assess changes in internal training load. Other factors may be required to estimate internal load such as: biomarkers, blood lactate, creatine kinase, etc. Strong relationships between PO_{30} and the two measures of internal load may not have been established in the current study due to the small increase in PO_{30} and large variance in this increase (mean difference 15 ± 14 W). However, even though the increase may appear small and non-significant at a group level it could translate to a significant increase/decrease in the field with regards to rowing performance. As reported by Driller *et al.* (2009) coefficient of variance is used to determine the worthwhile change in performance, which has been stated to be for mean power for 2km time trial, time to completion for 2 km time trial, VO_{2peak}, $PO_{4mmol/L}$, and PO_{peak} as 2 %, 1 %, 2.2 %, 1 %, and 2 %, respectively. Similarly, Paton and Hopkins (2006) stated that in cyclists a worthwhile effect is a change in 5 %. Therefore, a stronger relationship may have been established by utilising the coefficient of variation instead of absolute mean difference.

On a group level the PO_{30} follow a similar trend to the average of ARSS recovery construct scores (Figure 4.6 and 4.8). Both scores decrease towards week-4 and increase in week-11, possibly indicating that the lower and higher PO_{30} wattages could be due to athletes' recovery status (i.e. less recovered – lower PO_{30} wattage, and visa-versa), suggesting that the ARSS could be used to monitor fatigue and under recovery and/or performance or the PO_{30} can be used to monitor stress (fatigue) and recovery (as physical readiness). Smith *et al.* (2011), similarly used weekly 30 min all-out test in elite rowers (10-male 21-30 y; and 10-female 19-31 y) to determine performance, fatigue and overreaching/overtraining in a 4-week overload period.

Nonetheless, Issurin (2010), informs about the importance of changes in training load in a block-periodized method over the season to help the athlete develop targeted abilities in a controlled manner. This prevents the athlete from getting overtrained, while still getting the required adaptations to build the next phase on. Within the current study, looking at $sRPE_{TL}$ as an example training load, there is statistical significance determined for weeks 9 - 11 compared to weeks 6 - 7 but the training load plateaus from week-12 onwards (Table 4.1) questioning the variability in training load over the 15-week study period which may also limit the ability to assess the changes in internal training load in response to the external training load.

In conclusion, HR_{TL} has been determined to be moderately sensitive to the dose-response to training as reflected in sub-maximal performance indicating that, in the population investigated, HR_{TL} has more potential to be a valid method to monitor changes in internal training load than $sRPE_{TL}$ which was not sensitive to the dose-response to training as reflected in sub-maximal performance.

5.4. Relationship between recovery-stress scales and training load

Another main finding of the study is that only one construct (i.e. *Physical Performance Capacity*) had a significant relationship with $sRPE_{TL}$ (r = 0.784), with no other statistically significant relationships determined between the internal training load measures and the ARSS questionnaire, indicating that the ARSS questionnaire is unable to monitor changes in the weekly training load in this population.

Due to no distinct peaks found in the ARSS constructs the weeks that the RESTQ-76 was administered, the results will not be reported. The results from internal training load measures and the ARSS are similar to what Saw *et al.* (2016) found in their review about subjective and objective measures of training load: that the subjective and objective measures (i.e. markers of endocrine, erythrocytes, immune, inflammation and muscle damage) generally did not correlate with each other. Saw *et al.* (2016) also show that subjective measures (i.e. questionnaires) are more consistent and sensitive than objective measures in measuring training load, reflecting both acute and chronic changes in athlete well-being. In the review it was identified that subjective measures were found to consistently identify under recovery with acute increases with training responses (and therefore training load) and improved recovery with acute reduction in training. In the current study, only the relationships with internal training load (i.e. HR_{TL} and $sRPE_{TL}$) was compared to ARSS.

The inability of the questionnaires to determine a relationship does not necessarily indicate that the questionnaires are not useful. It could possibly rather indicate that due to the small sample size and the variability of scores between participants (example in Appendix 11.9) that the questionnaire cannot be used on a group level (i.e. many responses lie outside of the ± SD parameters determined) but should be investigated for each individual athlete separately. The questionnaires may also not be sensitive to the acute changes in training load within the current study but could be with chronic (which is undetermined).

The relationship between $sRPE_{TL}$ and *Physical Performance Capacity* construct (r = 0.784), has a shared variance of 62 % but with no other significant relationships the questionnaire it is concluded that unable to track the training load. This contradicts previous research from Collette *et al.* (2018) who found a significant relationship ($p <$ 0.05) between $sRPE_{TL}$ and ARSS constructs in 5-female high-performance swimmers (21 ± 2.8 y; 60.1 ± 6.5 kg) over a 17-week monitoring period of different periodization phases (including a 16-week training camp). In the study ARSS was completed every morning before training, and $sRPE_{TL}$ (i.e. sRPExDuration; and sRPExDistance [km]) and acute:chronic workload ratio (using $sRPE_{TL}$ methods) was determined for every training session. They found $sRPE_{TL}$, especially $sRPE_{distance}$, had the stronger relationship with the recovery-stress state of the ARSS constructs (i.e. mean cross-correlation coefficient in: *Physical Performance Capacity* = 0.39 [$sRPE^{km}$]*; Overall Recovery* = -0.36 [$sRPE^{km}$]*; Muscle Stress* = 0.41 [sRPE] and = 0.52 [$sRPE^{km}$]*;* and *Overall Stress* [$sRPE^{km}$]; less so in remaining constructs = ±0.23) than the acute:chronic workload ratio (= ±0.23). The absence of a statistically significant relationship (with $sRPE_{TL}$) within the current study could be due to the frequency of ARSS completion (i.e. daily vs. weekly). Indicating that the ARSS could be sensitive enough to detect changes in acute daily training load but not acute accumulated weekly training load. This could also indicate that acute weekly training load cannot be compared to an ARSS only performed on one day of the week. Another reason could be ARSS is not sensitive enough to determine acute training load on a group level within this population and intra-individual relationships should be investigated. Similar statistically significant relationships as in Collette *et al.* (2018) were determined in German junior female national field hockey players (Kölling *et al.*, 2015).

Similarly, there was no significant relationship determined between the ARSS and mean HR_{TL}. To the authors knowledge, no research has investigated the relationship between ARSS constructs and HR-TRIMP methods. However, based on previous studies that have demonstrated relationships between physiological stress (e.g. creatine kinase; increase in white blood cell count and granulocytes; and decrease in lymphocytes) and ARSS constructs allows us to conclude that generally when training load is increased, physiological stress is increased and the ARSS is sensitive to these changes (Puta *et al.*, 2018; Kellmann and Kölling, 2019). It is possible that the physiological stress was not enough to evoke changes, however, it is more likely that the variability in the data is causing the lack of significant relationships.

Kellmann and Kölling (2019) indicate for monitoring (especially long-term) it is best for the ARSS results to be regarded individually (i.e. intra-individual) for each person and not in a group context as the scores for items differ strongly between individuals. Although as previously mentioned, it is very important to take both subjective and objective recovery-stress state into consideration when monitoring athletes (Saw *et al.*, 2016). The measures should be used in conjunction to complement each other as monitoring training is not solemnly dependent on either subjective or objective factors.

Therefore, the ARSS is not sensitive enough to determine acute responses in training load or submaximal performance and, as previously stated, should be investigated individually for each athlete (Kellmann and Kölling, 2019).

5.5. Quantifying burnout levels with the ABQ

There were no statistically significant differences ($p > 0.05$) determined for ABQ mean differences from pre- to post-study. As the mean scores were low for all 3 constructs with no significant difference between pre and post it indicates that the athletes' on a group level were not experiencing burnout in the monitored period: *Reduced sense of accomplishment* pre - 2.28 ± 0.56 and post - 2.92 ± 0.83; *Emotional/Physical exhaustion* pre - 2.97 ± 0.67 and post - 3.27 ± 0.61; and *Devaluation of sport* pre - 1.72 ± 0.55 and post - 2.38 ± 0.79 (Figure 4.11). However, there was an increase in percentage of participants from pre to post that experience burnout levels of a scores 3 and above: *Reduced sense of accomplishment* pre - 8.33 and post - 54.33 %, *Emotional/Physical exhaustion* pre - 41.67 and post - 75.00 %, *Devaluation of sport* pre - 0 and post - 16.67 %. The absence of a significant change could be due to the ABQ being completed within the preparation phase (i.e. stress from sport is already increased) and not pre-season (i.e. less/no stress from sport) where they were not rowing.

Although only 8 % ($n = 1$) of the group experience high burnout levels in all 3 constructs for post-study assessment, 83 % experienced high burnout levels in either 1 or 2 constructs (42 % in each). This is greater than that experienced by Dubuc-Charbonneau *et al.* (2014), where only 1.4 % indicated high burnout levels in all 3 constructs within a cohort of 145 student-athletes. This could be explained by the small sample size within the current study or that the athletes had negative motivational trend, such as the swimmer in Dubuc-Charbonneau *et al.* (2014) who experienced higher burnout levels. The researchers conducted the study at 2 universities in Canada from different sports and year of attendance at university. They found no significant difference between university course and burnout levels. However, found significant differences ($p < 0.05$)

between gender for construct *Emotional/Physical exhaustion* (i.e. females experienced significantly higher scores), and between sports for constructs *Emotional/Physical exhaustion* and *Devaluation of sport* (i.e. swimmers and basketball players experienced higher levels compared to hockey players and fencers). Which is similar to what the current study found with higher burnout levels scores in *Emotional/Physical exhaustion* in pre- and post-results. According to Heidari (2013), who determined burnout levels in international high-performance female athletes, there are two factors that may contribute to the higher levels of burnout: i) females may be less capable of coping with physical and mental stress to their male counterparts; and ii) within the study – female athletes were less successful in international competition than their male counterparts which may have led to feelings of failure, inefficacy and reduced accomplishment.

Creating a needs satisfaction sporting environment for the athletes could promote their self-determined motivation and increase the quality of motivation, which could possibly lead to lower burnout scores (Lonsdale *et al.*, 2009; Lemyre *et al.*, 2016). Fortunately, no athletes dropped out of the sport due to burnout. This could possibly be explained by a built up psychological resilience (Moen *et al.*, 2019). Burnout does not just occur in sport, but can also occur in academic situations, therefore it is important to consider the academic stress that the student-athletes experience. As Dubuc-Charbonneau *et al.* (2014) stated, the demand on student-athletes are elevated during the academic year and competitive season.

5.6. Quantifying academic stress

Using 4 questions from 2 constructs of the Perception of Academic Stress scale there was no relationship determined with training load measures, recovery-stress scales, or a determined significant change during the exam period (weeks 4 - 5). Although, it was not recorded whether all participants had exams or deadlines during the exam period. There was only a significant difference determined over time for *Time restraints* with the difference determined between weeks 1 and 7 (p = 0.035, -0.19 ± 1.01 au).

Figure 4.11 indicates that the exam period in week 4 - 5 did not create a spike or reaction in the measures. This could be that the questionnaire only works as a whole, or that the questions asked are not specific enough to the stress that the athletes experience. This does not indicate that the questionnaire does not work, but rather that it is required as a whole to determine the academic stress. In the current study, it was determined that it would be best not to use the full questionnaire as the ARSS contains 32 questions and adding the full 20 question Perception of Academic Stress scale would create a larger questionnaire to complete weekly. This could lead to questionnaire fatigue and therefore a decrease in compliance and accuracy of results (Halson, 2014).

However, the *Overall Stress/Recovery* constructs from the ARSS did vary over the exam period, although not significantly, to follow the trend of increasing stress levels. This may indicate that the ARSS could be sensitive to academic stress as well. Further research would be required to determine whether this is true.

6. Limitations

There are several limitations of the current study, firstly, the relationships were not evaluated on an individual basis to determine the sensitivity of the ARSS to track training load. Similarly, the HR_{TL} method was also not individualised to each athlete but based on $\%HR_{max}$, which could hinder the training load due to under or over estimating training load score. Secondly, HR_{TL} could only be used for aerobic and steady state exercise; where $sRPE_{TL}$ could be implemented to track all the modes, intensities and types of training. Therefore, a direct comparison could not be made between internal training load methods. In hindsight, $sRPE_{TL}$ of the aerobic and steady state exercise could only have been compared with HR_{TL}. The accuracy of $sRPE_{TL}$ is also a limitation as some participants relied on recall that was longer than 30 min after training (as discussed in section 5.2.2), with some estimating that only 20 % of the answers meeting the stipulation of assessing $sRPE_{TL}$. This would hinder the $sRPE_{TL}$ score determined and possibly underestimate training load (i.e. training stress). Ideally, the coach would have retrieved the sRPE scores after a session, however, due to the time pressure set on the coach, the coach did not have time to collect sRPE of each athlete privately or at all. For resistance sessions the weighting factors are specific to this group of athletes based on their training goals, therefore cannot be translated to other populations. Lastly, due to technical issues (Appendix 11.4). HR_{TL} may have been underestimated by as much as 20 % for some athletes.

7. Conclusion

In conclusion, the current study found moderate significant relationships between distance and HR_{TL} and HR_{TL} and mean change in PO_{30} indicating that it has potential to be a sensitive measure to changes in internal training load in the population investigated in the current study. Although $sRPE_{TL}$ had a significant relationship with distance, it had no significant relationship with combined distance and volume load of resistance training and mean change in PO_{30} indicating that it is not a sensitive measure to changes in internal training load in the population investigated in the current study. However, caution should be taken when extrapolating these findings to the other populations due to the small sample size. Within this population, the results suggest that this recovery-stress scale (i.e. ARSS) was unable to replace internal training load measures at a group level as only the *Physical Performance Capacity* construct had a significant relationship with $sRPE_{TL}$, with no other relationships being determined between constructs and training load. However, this result may be due to individual variation in both training load and recovery-stress scale measures; further analyses of the data collected is required to determine whether they can be used within this population at an individual level. Fifty-percent of the current population experienced high burnout levels in the post-study ABQ, with the highest being in the *'Emotional/physical exhaustion'* construct.

8. Practical Application

Findings from the current study suggest that HR_{TL} can be used in a group setting to monitor the internal training load of athletes. Therefore, coaches could implement this method of HR_{TL} on a group level to track athletes training loads, although a great limitation to the HR_{TL} method is that the HR equipment is expensive and not all athletes can afford the equipment. That is why the $sRPE_{TL}$ method is easier and cheaper, but in the current study was not sensitive enough to the dose-response of PO_{30} and this could be due to recall and therefore over-/underestimations of the true perception of exertion. However, the ARSS on a group level was unable to track the training load, therefore might be better utilised on an individual level. The individual responses and intra-individual relationships would need to be examined to provide coaches with a means of individualising training for each athlete.

9. Future research

Considering the limitations, future research should focus on the individual responses for athletes instead of on a group level, this will help with individualising of training for athletes. The methods to estimate training load investigated in the current study as well as other developed estimate of training load should be compared with the dose-response in fitness and performance measures to determine the validity and strength of these measures to estimate internal training loads and any variations over time. Research should be expanded to determine relationships between different methods to estimate training load and performance and/or fitness with larger sample sizes and/or with certain biomarkers associated with internal stress in response to training such as cortisol, creatine kinase, testosterone, glutamine, etc. This will hopefully determine the theoretical underpinning of training load methods. By investigating whether the training load and performance and/or fitness relationships are exponential or inverted U in nature. This will help promote the practical application of working with coaches to determine individual athletes' thresholds for training load before performance and/or fitness is hindered. This would be easier to determine in physiological endurance sports such as cycling and marathon running, but could possibly be more difficult in a sport such as rowing due to the technicality of the sport.

Research should be conducted on chronic training loads for rowers using rolling training load average methods. More research is required for the relationships between acute and chronic training load responses compared to recovery-stress scales such as the ARSS, especially for accumulated training load scores (i.e. a week) compared to a single questionnaire. Therefore, measuring the feasibility of using ARSS methods to track training load instead of other training load methods such as the ones implemented in the current study (e.g. $sRPE_{TL}$; HR-TRIMP; and volume load for resistance training). The ARSS should also be investigated on the sensitivity to academic stress to improve coaches of student-athletes understanding and ability to assess the overarching stress of athletes.

As mentioned before, athletes may require differing optimal training intensity distributions therefore a 'threshold' (e.g. 50:50, 60:40, 70:30, 80:20 %) for different endurance sports, different competitive levels and training history should be investigated. This would guide future endurance coaches to individualising training even more for athletes within group as well as individual settings, promoting 'smarter' training rather than 'harder' and preventing negative effects of overtraining.

10. References

Akça, F. (2014) ‘Prediction of Rowing Ergometer Performance from Functional Anaerobic Power, Strength and Anthropometric Components’, *Journal of Human Kinetics*, 41(1), pp. 133–142. doi: 10.2478/hukin-2014-0041.

Anderson, A. G. and Lavallee, D. (2008) ‘Applying the theories of reasoned action and planned behavior to athlete training adherence behavior’, *Applied Psychology*, 57(2), pp. 304–312. doi: 10.1111/j.1464-0597.2007.00310.x.

Bedewy, D. and Gabriel, A. (2015) ‘Examining perceptions of academic stress and its sources among university students: The Perception of Academic Stress Scale’, *Health Psychology Open*, 2(2). doi: 10.1177/2055102915596714.

Bell, L. and Ingle, L. (2013) ‘Psycho-physiological markers of overreaching and overtraining in endurance sports: a review of the evidence’, *Medicina Sportiva*, 17(2), pp. 81–97. doi: 10.5604/17342260.1055272.

Borresen, J. and Lambert, M.I., (2008) ‘Quantifying training load: A comparison of subjective and objective methods’, *International Journal of Sports Physiology and Performance*, 3(1), pp. 16–30.

Borresen, J. and Lambert, M. I. (2009) ‘The Quantification of Training Load , Effect on Performance’, *Sports Med*, 39(9), pp. 779–795.

Buchheit, M. (2014) ‘Monitoring training status with HR measures: Do all roads lead to Rome?’, *Frontiers in Physiology*, 5 FEB(February), pp. 1–19. doi: 10.3389/fphys.2014.00073.

Capostagno, B., Lambert, M. I. and Lamberts, R. P. (2019) ‘Analysis of a Submaximal Cycle Test to Monitor Adaptations to Training: Implications for Optimizing Training Prescription’, *The Journal of Strength and Conditioning Research*, Preprintin, pp. 1–7.

Carfagno, D. G. and Hendrix, J. C. (2014) ‘Overtraining Syndrome in the Athlete’, *Current Sports Medicine Reports*, 13(1), pp. 45–51. doi: 10.1249/jsr.0000000000000027.

Collette, R., Kellmann, M., Ferrauti, A., Meyer, T., and Pfeiffer, M. (2018) ‘Relation between training load and recovery-stress state in high-performance swimming’, *Frontiers in Physiology*, 9(JUL), pp. 1–14. doi: 10.3389/fphys.2018.00845.

Cureton, K. J. (2009) ‘Athlete Burnout: A Physiological Perspective’, *Journal of Intercollegiate Sport*, 2(1), pp. 31–34. doi: 10.1123/jis.2.1.31.

Day, M. L., McGuigan, M.R., Brice, G., and Foster, C. (2004) ‘Monitoring exercise intensity during resistance training using the session RPE scale’, *Journal of Strength and Conditioning Research*, 18(2), pp. 353–358.

Dellavalle, D. M. and Haas, J. D. (2013) ‘Quantification of training load and intensity in female collegiate rowers: Validation of a daily assessment tool’, *Journal of Strength and Conditioning Research*, 27(2), pp. 540–548. doi: 10.1519/JSC.0b013e3182577053.

Driller, M. W., Fell, J.W., Gregory, J.R., Shing, C.M., and Williams, A.D. (2009) ‘The effects of high-intensity interval training in well-trained rowers’, *International Journal of Sports Physiology and Performance*, 4(1), pp. 110–121. doi: 10.1123/ijspp.4.1.110.

Dubuc-Charbonneau, N., Durand-Bush, N. and Forneris, T. (2014) ‘Exploring levels of student-athlete burnout at two Canadian universities’, *Canadian Journal of Higher Education Revue canadienne*, 44(2), pp. 135–151.

Esteve-Lanao, J., Foster, C., Seiler, S., and Lucia, A. (2007) ‘Esteve-Lanao et al (2007) Impact of training intensity distribution on performance in endurance athletes JSCR 21(3).pdf’, 21(3), pp. 943–949. doi: 10.1519/R-19725.1.

Eston, R. G. (2012) ‘Use of Ratings of Perceived Exertion in Sports’, *International Journal of Sports Physiology & Performance*, 7, pp. 175–182. doi: 10.1519/1533-4287(2001)015<0320:SSPFRP>2.0.CO;2.

Faude, O., Kindermann, W. and Meyer, T. (2009) ‘Lactate threshold concepts: How valid are they?’, *Sports Medicine*, 39(6), pp. 469–490. doi: 10.2165/00007256-200939060-00003.

Foster, C. (1998) ‘Monitoring training in athletes with reference to overtraining syndrome’, *Med. Sci. Sports Exerc.*, 30(7), pp. 1164–1168.

Foster, C., Florhaug, J., Franklin, J., Gottschall, L., Hrovatin, L.A., Parker, S., Doleshal, P., and Dodge, C. (2001) ‘A new approach to monitoring exercise training. Journal of Strength and Conditioning Research’, *Journal of Strength and Conditioning Research*, 15(1), pp. 109–115.

Genner, K. M. and Weston, M. (2014) ‘A comparison of workload quantification methods in relation to physiological responses to resistance exercise’, *Journal of Strength and Conditioning Research*, 28(9), pp. 2621–2627. doi: 10.1519/JSC.0000000000000432.

Grant, C.C., Janse van Rensburg, D.C., Collins, R., Wood, P.S., and Du Toit, P.J. (2012) ‘The Profile of Mood State (POMS) questionnaire as an indicator of Overtraining Syndrome (OTS) in endurance athletes’, *African Journal for Physical*, pp. 23–32.

Guellich, A., Seiler, S. and Emrich, E. (2009) ‘Training Methods and Intensity Distribution of Young World-Class Rowers’, *International Journal of Sports Physiology and Performance*, 4(4), pp. 448–460. doi: 10.1123/ijspp.4.4.448.

Halson, S. L. (2014) ‘Monitoring Training Load to Understand Fatigue in Athletes’, *Sports Medicine*, 44, pp. 139–147. doi: 10.1007/s40279-014-0253-z.

Hamlin, M. J., Wilkes, D., Elliot, C.A., Lizamore, C.A., and Kathiravel, Y. (2019) ‘Monitoring training loads and perceived stress in young elite university athletes’, *Frontiers in Physiology*, 10(JAN), pp. 1–12. doi: 10.3389/fphys.2019.00034.

Heidari, S. (2013). ‘Gender differences in burnout in individual athletes’, *European Journal of Experimental Biology,* 3(3), pp. 583-588.

Herman, L., Foster, C., Maher, M.A., Mikat, R.P., and Porcari, J.P. (2006) ‘Validity and reliability of the session RPE method for monitoring exercise training intensity’, *South African Journal of Sports Medicine*, 18(1), pp. 14–17. doi: 10.17159/2078-516x/2006/v18i1a247.

Hosea, T. M. and Hannafin, J. A. (2012) ‘Rowing Injuries’, *Sports Health*, 4(3), pp. 236–245. doi: 10.1177/1941738112442484.

Impellizzeri, F. M., Rampinni, E., Coutts, A.J., Sassi, A., and Marcora, S.M. (2004). ‘Use of RPE-based training load in soccer’, *Medicine and Science in Sports and Exercise*, 36(6), pp. 1042–1047. doi: 10.1249/01.MSS.0000128199.23901.2F.

Impellizzeri, F. M., Marcora, S., and Coutts, A.J. (2019). ‘Internal and external training load: 15 years on’. *International Journal of Sport Physiology and Performance.* 14(2), pp. 270-273.

Ingham, S. A., Whyte, G.P., and Nevill, A.M. (2002) ‘Determinants of 2,000 m rowing ergometer performance in elite rowers’, *European Journal of Applied Physiology*, 88(3), pp. 243–246. doi: 10.1007/s00421-002-0699-9.

Issurin, V. B. (2010) ‘New Horizons for the Methodology and Physiology of Training Periodization’, *Sports Medicine*, 40(9), pp. 803–805. doi: 10.2165/11535130-000000000-00000.

Johansson, R. E., Adolph, S. T., Swart, J., and Lambert, M. I. (2020). Accuracy of GPS sport watches in measuring distance in n ultramarathon running race. *International Journal of Sport Science & Coaching.* 0(0), pp. 1-8. doi: 10.1177/1747954119899880

Jürimäe, J., Mäestu, J., and Jürimäe, T. (2001). Anaerobic threshold, maximal aerobic power and rowing performance in male competitive rowers. *Journal of Human Kinetics*. 5(1), pp. 3-11.

Jürimäe, J., Purge, P., Mäestu, J., Sööt, T., and Jürimäe, T. (2002). Monitoring of Stress in Trained Male Rowers. *Journal of Human Kinetics*, 7, pp. 11–18.

Kellmann, M. (2010) ‘Preventing overtraining in athletes in high-intensity sports and stress/recovery monitoring’, *Scandinavian Journal of Medicine and Science in Sports*, 20(SUPPL. 2), pp. 95–102. doi: 10.1111/j.1600-0838.2010.01192.x.

Kellmann, M., Bertollo, M., Bosquet, L., Brink, M., Coutts, A.J., Duffield, R., Erlacher, D., Halson, S.L., Hecksteden, A., Heidari, J., Kallus, K. W., Meeusen, R., Mujika, I., Robazza, C., Skorski, S., Venter, R., and Beckmann, J. (2018). ‘Recovery and performance in sport: Consensus statement’, *International Journal of Sports Physiology and Performance*, 13(2), pp. 240–245. doi: 10.1123/ijspp.2017-0759.

Kellmann, M. and Günther, K. D. (2000) ‘Changes in stress and recovery in elite rowers during preparation for the Olympic Games’, *Medicine and Science in Sports and Exercise*, 32(3), pp. 676–683. doi: 10.1097/00005768-200003000-00019.

Kellmann, M. and Kallus, K.W. (2001). Recovery-stress questionnaire for athletes: User Manual. *Human Kinetic,* United States of America.

Kellmann, M. and Kölling, S. (2019). Recovery and stress in sport: A manual for testing and assessment. *Routledge*, Oxfordshire, United Kingdom.

Kölling, S., Hitzschke, B., Holst, T., Ferrauti, A., Meyer, T., Pfeiffer, M., and Kellmann, M. (2015) ‘Validity of the acute recovery and stress scale: Training monitoring of the German Junior National Field Hockey team’, *International Journal of Sport Science & Coaching*, 10(2+3), pp. 529–542.

Lemyre, P.-N., Treasure, D. C. and Roberts, G. C. (2016) ‘Influence of Variability in Motivation and Affect on Elite Athlete Burnout Susceptibility’, *Journal of Sport and Exercise Psychology*, 28(1), pp. 32–48. doi: 10.1123/jsep.28.1.32.

Lonsdale, C., Hodge, K. and Rose, E. (2009) ‘Athlete burnout in elite sport: A self-determination perspective’, *Journal of Sports Sciences*, 27(8), pp. 785–795. doi: 10.1080/02640410902929366.

Lucía, A., Hoyos, J., Santalla, A., Earnest, C., and Chicharro, J.L. (2003) ‘Tour de France versus Vuelta a España: Which is harder?’, *Medicine and Science in Sports and Exercise*, 35(5), pp. 872–878. doi: 10.1249/01.MSS.0000064999.82036.B4.

Mäestu, J., Jürimäe, J., Kteegipuu, K., and Jürimäe, T. (2006) ‘Changes in Perceived Stress and Recovery during Heavy Training in Highly Trained Male Rowers’, *The Sport Psychologist*, 20(1), pp. 24–39. doi: 10.1123/tsp.20.1.24.

Mäestu, J., Jürimäe, J. and Jürimäe, T. (2005) ‘Monitoring of Performance and Training in Rowing’, *Sports Medicine*, 35(7), pp. 597–617.

Marston, K.J., Peiffer, J.J., Newton, M.J., and Scott, B.R. (2017). ‘A comparison of traditional and novel metrics to quantify resistance training’. *Scientific Reports*. 7(5606) pp. 1-8.

McNeely, E. (2012). Rowing ergometer physiological tests do not predict on-water performance. *Sport Journal.* 15(1), pp. 1

Mikulic, P. (2011) ‘Maturation to elite status: A six-year physiological case study of a world champion rowing crew’, *European Journal of Applied Physiology*, 111(9), pp. 2363–2368. doi: 10.1007/s00421-011-1870-y.

Mikulić, P., Smoljanović, T., Bojanić, I., Hannafin, J., and Pedišić, Ž. (2009) 'Does 2000-m rowing ergometer performance time correlate with final rankings at the World Junior Rowing Championship? A case study of 398 elite junior rowers', *Journal of Sports Sciences*, 27(4), pp. 361–366. doi: 10.1080/02640410802600950.

Moen, F., Myhre, K., Klöckner, C.A., Gausen, K., and Sandbakk, Ø. (2017) 'Physical, Affective and Psychological determinants of Athlete Burnout.', *Sport Journal*, (April).

Moen, F., Hrozanova, M., Stiles, T.C., Stenseng, F. (2019) 'Burnout and Perceived Performance Among Junior Athletes—Associations with Affective and Cognitive Components of Stress', *Sports*, 7(7), p. 171. doi: 10.3390/sports7070171.

Murray, A. (2017) 'Managing the Training Load in Adolescent Athletes Athlete Development : A Modern Training Young Athletes ': *International Journal of Sports Physiology and Performance*, 12, pp. 42–49.

Murray, N.B., Gabbett, T.J., Townshend, A.D., and Blanch, P. (2017) 'Calculating acute: Chronic workload ratios using exponentially weighted moving averages provides a more sensitive indicator of injury likelihood than rolling averages', *British Journal of Sports Medicine*, 51(9), pp. 749–754. doi: 10.1136/bjsports-2016-097152.

Nässi, A., Ferráuti, A., Meyer, T., Pfeiffer, M., and Kellmann, M. (2017) 'Development of two short measures for recovery and stress in sport', *European Journal of Sport Science*, 17(7), pp. 894–903. doi: 10.1080/17461391.2017.1318180.

Newell, J., Higgins, D., Madden, N., Cruickershank, J., Einbeck, J., McMillan, K., McDonald, R. (2007) 'Software for calculating blood lactate endurance markers', *Journal of Sports Sciences*, 25(12), pp. 1403–1409. doi: 10.1080/02640410601128922.

Nolte, V. (2011) '*Rowing Faster: Serious training for serious rowers.'* 2nd Ed. United States of America, Human Kinetics, pp. 71-80.

Paton, C. D. and Hopkins, W. G. (2006) 'Variation in performance of elite cyclists from race to race', *European Journal of Sport Science*, 6(1), pp. 25–31. doi: 10.1080/17461390500422796.

Pelka, M. and Kellmann, M. (2017) 'Relaxation and Recovery in Sport and Performance', 1(August), pp. 1–22. doi: 10.1093/acrefore/9780190236557.013.153.

Perkins, C.C.D., Pivarnik, J.M. (2003) (Abstract) 'Physiological profiles and performance predictors of a women's NCAA rowing team', *The Journal of Strength and Conditioning Research*, 17(1), pp. 173-176.

Plews, D. J., Laursen, P.B., Kilding, A.E., and Buccheit, M. (2014) 'Heart-rate variability and training-intensity distribution in elite rowers', *International journal of sports physiology and performance*, 9(6), pp. 1026–1032. doi: 10.1123/ijspp.2013-0497

Pritchett, R., Green, J.M., Wickwire, P.J., Pritchett, K.L., and Kovacs, M.S. (2009) 'Acute and session RPE responses during resistance training: Bouts to failure at 60% and 90% of 1RM', *South African Journal of Sports Medicine*, 21(1), pp. 23–26. doi: 10.17159/2078-516x/2009/v21i1a304.

Puta, C., Steidten, T., Baumbach, P., Wöhrl, T., May, R., Kellmann, M. (2018) 'Standardized assessment of resistance training-induced subjective symptoms and objective signs of immunological stress responses in young athletes', *Frontiers in Physiology*, 9(JUN), pp. 1–11. doi: 10.3389/fphys.2018.00698.

Raedeke, T. D. and Smith, A. L. (2001) 'Development and Preliminary Validation of an Athlete Burnout Measure', *Journal of Sport & Exercise Psychology*, 23, pp. 281–306. Available at: http://eds.a.ebscohost.com/eds/pdfviewer/pdfviewer?vid=4&sid=f28ffb85-eb2d-4513-9ec2-8a5e09ee6d11@sessionmgr4005&hid=4211.

Raglin, J. S., Morgan, W. P. and Luchsinger, A. E. (1990) 'Mood and self-motivation in successful and unsuccessful female rowers', *Medicine and Science in Sports and Exercise*, 22(6), pp. 849–853. doi: 10.1249/00005768-199012000-00018.

Reader, C., Wiewelhove, T., Simola, R. Á. D. P., Kellmann, M., Meyer, T., Pfeiffer, M., and Ferrauti, A., (2016) 'Assessment of fatigue and recovery in male and female athletes after 6 days of intensified strength training', *Journal of Strength and Conditioning Research,* 30(12), pp. 3412-3427.

Saw, A. E., Main, L. C. and Gastin, P. B. (2016) 'Monitoring the athlete training response: Subjective self-reported measures trump commonly used objective measures: A systematic review', *British Journal of Sports Medicine*, 50(5), pp. 281–291. doi: 10.1136/bjsports-2015-094758.

Scott, B. R., Duthie, G.M., Thornton, H.R., and Dascombe, B.J. (2016) 'Training Monitoring for Resistance Exercise: Theory and Applications', *Sports Medicine*. Springer International Publishing, 46(5), pp. 687–698. doi: 10.1007/s40279-015-0454-0.

Scott, T. J., Black, C., Quinn, J., and Coutts, A.J. (2013) 'Validity and reliability of the session-RPE method forquantifying training in australian football: A comparison of the CR10 and CR100 scales', *Journal of Strength and Conditioning Research*, 27(1), pp. 270–276. doi: 10.1519/JSC.0b013e3182541d2e.

Seiler, K. S. and Kjerland, G. Ø. (2006) 'Quantifying training intensity distribution in elite endurance athletes: Is there evidence for an "optimal" distribution?', *Scandinavian Journal of Medicine and Science in Sports*, 16(1), pp. 49–56. doi: 10.1111/j.1600-0838.2004.00418.x.

Seiler, S. (2010) 'What is Best Practice for Training Intensity and Duration Distribution in Endurance Athletes', *International Journal of Sports Physiology and Performance*, 5, pp. 276–291.

Seiler, S., Haugen, O. and Kuffel, E. (2007) 'Autonomic recovery after exercise in trained athletes: intensity and duration effects', *Medicine & Science in Sports & Exercise*, 39(8), pp. 1366–1373. doi: 10.1249/mss.0b013e318060f17d.

Smith, T. B. and Hopkins, G. W. (2012) ‘Measures of Rowing Performance.’, *Sports Medicine*, 42(4), pp. 343–358. doi: 10.2165/11597230-000000000-00000.

Smith, T. B., Hopkins, W. G. and Lowe, T. E. (2011) ‘Are there useful physiological or psychological markers for monitoring overload training in elite rowers?’, *International Journal of Sports Physiology and Performance*, 6(4), pp. 469–484. doi: 10.1123/ijspp.6.4.469.

Smoljanovic, T., Bojanic, I., Hannafin, J.A., Hren, D., Delimar, D., and Pecina, M. (2009) ‘Traumatic and overuse injuries among international elite junior rowers’, *American Journal of Sports Medicine*, 37(6), pp. 1193–1199. doi: 10.1177/0363546508331205.

Steinacker, J. M. (1993) ‘Physiological aspects of training in rowing’. *Journal of Sports Medicine*. 14, pp. S3–S10.

Steinacker, J. M. (1998) ‘Training of rowers before world championships’, *Medicine & Science in Sports & Exercise*, 30(7), pp. 1158–1163.

Stöggl, T. L. and Sperlich, B. (2015) ‘The training intensity distribution among well-trained and elite endurance athletes’, *Frontiers in Physiology*, 6(OCT), p. 295. doi: 10.3389/fphys.2015.00295.

Stöggl, T. and Sperlich, B. (2014) ‘Polarized training has greater impact on key endurance variables than threshold, high intensity, or high volume training’, *Frontiers in Physiology*, 5 FEB(February), pp. 1–9. doi: 10.3389/fphys.2014.00033.

Tanner, R.K. and Gore, C.J. (2013). Physiological tests for elite athletes. 2nd Ed. *Human Kinetics*,

Tran, J., Rice, A.J., Main, L.C., and Gastin, P.B. (2014) ‘Development and implementation of a novel measure for quantifying training loads in rowing: The T2minute method’, 28(4), pp. 1172–1180.

Tran, J., Rice, A.J., Main, L.C., and Gastin, P.B. (2015a) 'Convergent validity of a novel method for quantifying rowing training loads', *Journal of Sports Sciences*, 33(3), pp. 268–276. doi: 10.1080/02640414.2014.942686.

Tran, J., Rice, A.J., Main, L.C., and Gastin, P.B. (2015b) 'Profiling the training practices and performance of elite rowers', *International Journal of Sports Physiology and Performance*, 10(5), pp. 572–580. doi: 10.1123/ijspp.2014-0295.

Yoshiga, C. C. and Higuchi, M. (2003) 'Rowing performance of female and male rowers', *Scandinavian Journal of Medicine and Science in Sports*, 13(5), pp. 317–321. doi: 10.1034/j.1600-0838.2003.00321.x.

11. Appendix

Appendix 11.1a: The age predicted percentages of HRmax of Bourdon in Australian Sport Institute book (2013) and Edward's TRIMP (1993) that correlate with blood lactate thresholds for training zones

	Bourdon		Edward's TRIMP (1993)
Training zone	Blood lactate threshold relationship	%HRmax	%HRmax
T1	<LT1	60-75	50-60
T2	Lower half between LT1 and LT2	75-84	60-70
T3	Upper half between LT1 and LT2	82-89	70-80
T4	LT2	88-93	80-90
T5	>LT2	92-100	90-100

Note: LT1 – lactate threshold 1; LT2 – lactate turnpoint/threshold 2; <LT1 – lower than lactate threshold 1; >LT2 – greater than lactate turnpoint/threshold 2; %HR_{max} – percentage of age predicted maximal heart rate; age predicted HR_{max} calculation – 220 – age.

Appendix 11.1b: Description of 5-intensity zone model with regards to adaptations:

Classically, endurance training zones are divided into a 5-zones model based on the adaptations associated with and functions of LT1 and LT2. Zone-1 is light aerobic (or recovery) training that is below LT1, the training is used for dynamic recovery purposes. Zone-2 is moderate aerobic (i.e. basic oxygen utilising) training that induces adaptations over time (e.g. increases in blood volume; aerobic enzyme activity; maximal cardiac output; and maximal ventilatory capacity). Zone-3 is heavy aerobic training (i.e. oxygen utilising training) that over time increases aerobic fitness (i.e. ability to work at higher rate for LT1) with adaptations such as: increases in maximum cardiac output; and maximum ventilatory capacity. Zone-4 is threshold training at LT2 and extended period of time in zone-4 will increase anaerobic fitness (i.e. ability to work at higher rate for LT2) and adaptations that occur over time are: e.g. improved buffering capacity; and race specific neuromuscular adaptations. Zone-5 is maximal aerobic (i.e. oxygen transporting) training above LT2 and can increases adaptations: e.g. maximum rate of glucose use; and improved buffering capacity.

Appendix 11.2: Equation sheet

HR-based:

Banister TRIMP:

Banister's TRIMP = D x HR ratio x Y **(Equation 1)**

Where:

HR ratio = $(HR_{ex} - HR_{rest})/(HR_{max} - HR_{rest})$

$Y = a.e^{bx}$

D = exercise duration [min]

HR_{ex} = *average HR during exercise [bpm]*

HR_{rest} = *resting HR [bpm]*

HR_{max} = *maximal HR [bpm]*

Y = intensity weighting factor [unitless]

a = sex-specific value (0.64 for men and 0.86 for women) [unitless]

e = Euler's number (2.718, at three decimal places) [unitless]

b = sex-specific value (1.92 for men and 1.67 for women) [unitless]

x = change in HR ratio [unitless]

Edwards TRIMP:

Edward's training load = $Z_1 + Z_2 + Z_3 + Z_4 + Z_5$ **(Equation 2)**

Where:

$Z_x = D_x \times F_{i(x)}$

Z_x = *load at intensity zone x [HR zones]*

D_x = *duration of training intensity x [min]*

F_m = *weighting factor of training mode [unitless]*

$F_{i(x)}$ = *weighting factor for intensity at zone x [unitless]*

Zone 1 = 50-60% $HR_{max,}$*-weighting factor 1*

Zone 2 = 60-70% HR_{max} *- weighting factor 2*

Zone 3 = 70-80% HR_{max} *– weighting factor 3*

Zone 4 = 80-90% HR_{max} ,-weighting factor 4

Zone 5 = 90-100% HR_{max},-weighting factor 5

Lucia's TRIMP:

Lucia's TRIMP = $(1 \times D_{Z1}) + (2 \times D_{Z2}) + (3 \times D_{Z3})$ **(Equation 3)**

Where:

D_x = duration of training intensity at zone x [min]

Zx = Zones (Z1 = below Ventilatory threshold, Z2 = between ventilatory threshold and respiratory compensation point, Z3 = above respiratory compensation point)

TID (%) (Seiler and Kjerland, 2006):

TID Zone 1 = (HR duration [min.deciminutes] in <LT1/total duration) x 100

(Equation 4)

TID Zone 2 = (HR duration [min.deciminutes] in >LT1/total duration) x 100

(Equation 5)

HR_{TL} using the estimated HR_{max} from the equation 220 – age (arbitrary units):

$\mathbf{HR_{TL}} = (Z1d \times 1) + (Z2d \times 2) + (Z3d \times 3) + (Z4d \times 4) + (Z5d \times 5)$ **(Equation 6)**

Where:

Z*n*d = duration (min) in zone *n*

Zones based on Table 3.2 in section 3.7.

Zone 1 = <75% HR_{max}

Zone 2 = 75 – 84% HR_{max}

Zone 3 = 82 – 89% HR_{max}

Zone 4 = 88 – 93 % HR_{max}

Zone 5 = 92 – 100% HR_{max}

Subjective TL:

RPE is based on Foster et al. (2001) RPE scale in Appendix 11.3

sRPE = global RPE for session x duration of training **(Equation 7)**

Strength and conditioning:

Volume load strength and conditioning sessions:

Volume load (Haff, 2010) = (*n*Reps x load x set) + (*n*Reps x load x set) + (*n*Reps x load x set) + … **(Equation 8)**

Volume load with weighted factor = (*n*Reps x load x set x *Fn*) + (*n*Reps x load x set x *Fn*) + (*n*Reps x load x set x *Fn*) + … **(Equation 9)**

Volume load with adjusted exercise = (*n*Reps x adjusted load x set x *Fn*) + (*n*Reps x adjusted load x set x *Fn*) + (*n*Reps x adjusted load x set x *Fn*) + … **(Equation 10)**

Where:
*n*Reps = repetitions of exercise *n*
Load = weight of load or body weight (kg)
Fn = factor determined by the demand put on the body compared to key exercises the back squat and deadlift (arbitrary units; Appendix 11.12)
Adjusted weight = body mass – (body mass x [percentage of decrease of difficulty from band/ 100]) (kg)
Resistance bands of different strengths were used to make the exercise easier by helping with the load (i.e. Blue = 45%, Purple/Green = 30%, and Red = 10% easier) and press-ups administered on the knees are 20% easier.

Example 1*:* athlete completed 4 sets of 6 reps of back squat with 20kg and completed 4 sets of 5 reps of chin-ups (body mass 72kg) using a purple resistance band:
Volume load = (6 x 20 x 4 x 1) + (5 x (72 – [72 x 0.30/100]) x 4 x 0.8) = 1286.4 arbitrary units

Injury:

Injury = sum of injury scores for the week **(Equation 11)**

Adherence

Adherence % = 100 – ([sum of adherence score / total number possible of adherence score] x 100) **(Equation 12)**

Where:
Total number possible for adherence is based on 1 session = 3 adherence score, therefore
e.g. 8 prescribed sessions per week would equal a total number of possible adherence score of 24 for the week.

Appendix 11.3: Foster *et al.* (2001) RPE scale

Rating of Perceived Exertion

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

Appendix 11.4: Summary of results for post study exit interviews in week 28 of longitudinal study from participants

Exit interviews were conducted on 11 out of 12 athletes, due to athlete not wanting to complete interview due to drop out of study from injury. Number of participants that stated answer is in brackets. Ten cm Visual Analogue Scales (VAS) and 5-point Likert-scales were implemented in the questionnaire.

Question 1: As this was a very involved study, what was your experience of it?

- Not intrusive to training (1)
- Helpful to see own data (5)
- Good, handy to record and save information (5)
- HR was easy to remember (2)
- RPE more difficult to remember to do it (1)
- Watches were good (1)
- Good incentives (1)
- Good that researchers helped athlete to understand response (HR) meaning (1)
- Quite an involved study (close contact/support) (1)
- Injury stuff helped athlete (1)
- A bit of a hassle sometimes (1)
- Support good (3)
- HR instant feedback (1)

Question 2.1: The study is trying to find methods to monitor training load, what would you say was the easiest method? (*Heart rate; Stress and Recovery questionnaires; RPE*)

Ranked:

1. Heart rate (11)
2. RPE
3. Questionnaires

Question 2.2: Why?

HR: (11)

- Explained more about training (2)

- In training feedback (7)
- See how hard you are working, esp. on water (1)
- Able to see data for sessions (4)
- Able to tell when ill or tired – know own norms and responses (2)
- Familiar with using watch for training – use to doing it (3)
- Could not cheat the system (1)
- HR continuous monitoring (1)
- Used for morning resting HR checked (2)
- More self-aware (1)
- Useful to use for recovery (1)

RPE: (3)

- Based on how athlete feels – allows for lying to coach (1)
- Subjective (2)
- Indicate a good/bad day (1)

Questionnaire: (1)

- Made athlete more aware of themselves while filling it out (2)

Question 3.1: How did you find the questionnaires?

- Could remember what stated the previous week and compared to those results instead of on the day of the questionnaire administration (2)
- ARSS questionnaires quite long (4), became tedious (1), boring (2), hassle (1)
- ARSS questionnaires difficult to fill out before training due to university commitments (e.g. lectures) (1)
- Questionnaires gave personal awareness (3)
- Repetitive – some questions are similar but rephrased (i.e. muscle soreness and muscle stiffness; tired and exhausted) (4)
- Felt different from doing it before training to doing it after training (1)
- Answering for on the day, so mood that day affected the results (1)
- Reminders worked in the beginning of study but were more ignored towards the end (1)
- No feedback – not helpful (2)
- Easy to fill out (3)
- Subjective – Likert scale did not feel specific to athlete (1)

- Always remembered feeling the same (1)

Question 3.2: How honest would you say you were with the questionnaires? (5-point Likert scale – 1- *Not honest at all* to 5- *Completely honest*; and a 10cm VAS scale from *Not honest at all* to *Completely honest*)

Likert-scale

4(5) 5(6)

VAS

75(1) 77(1) 78(1) 82(1) 90(1) 93(1) 97(4) 100(1)

Question 3.3: Why would you say that (3.2)?

- Could remember what stated the previous week and compared to those results instead of on the day of the questionnaire administration (2)
- Got bored while filling out the questionnaires (4)
- Missed doing it on the same day sometimes (4)
- Felt like I had to use recall once missed (4)
- Always remembered feeling the same (1)

Question 3.4: You were …% compliant with the questionnaires, is there a reason why you were not fully compliant?

86(1) 87(1) 89(2) 93(3) 96(2) 100(2)

- Busy day at university (2)
- Forgot (8)
- At GB training camp (1)
- Notification from researcher for reminders turned off (1)
- Saying will do it later (1)
- Bad mood, did not feel like doing it (1)
- Technical failure of computer (1)
- Easy to forget when on holiday to do questionnaires (1)

Question 4.1: How honest would you say you were with the RPE information? (5-point Likert scale – 1- *Not honest at all* to 5- *Completely honest*; and a 10cm VAS scale from *Not honest at all* to *Completely honest*)

Likert-scale

2(1) 3(3) 4(6) 5(1)

VAS

20(1) 58(1) 63(2) 67(1) 76(1) 78(1) 81(1) 83(1) 93(1) 100(1)

Question 4.2: Why would you say that (4.1)?

- Based on 24 - 48 hour recall (4)
- Similar session recall (2)
- Recall of up to a week (1)
- Recall of longer than a week (3)
- Busy period – not able to recall as accurately (1)
- Session clouded how tired athlete was afterwards (1)

Question 5.1: Could you recall a timeline of injuries? (individual to each person for cross-check)

- Yes, some (5)
- Yes, but very little (1)
- Yes, most recent (2)
- Not really (2)
- N/A (1)

Question 5.2: Is what you stated as injuries on the RPE recording sheet, a true reflection of your injuries or did you possibly feel the injuries coming on beforehand? (e.g. signs and symptoms or just when you were injured?)

- When it started before full onset (i.e. signs and symptoms) (3)
- Only when completely injured/ill (7)
- Ignore/did not state build up (1)
- N/A (1)

Question 6.1: What is a breakdown of your 30’ split times?

- Can’t remember (2)
- Yes, most recent one (1)
- Yes, at least 5 (1)
- Yes, beginning and end of season ones (7)

Question 6.2: What is a breakdown of your 2km times?

- Can’t remember (1)
- Yes, only one (4)
- Yes, most recent two (2)
- Yes, most recent three (3)
- Yes, all (1)

Question 6.3: What is a breakdown of your 5km times?

- Did not do (7)
- Yes, most recent one (2)
- Yes, most recent two (1)
- Completed, but can’t remember time (1)

Question 7: What would you say is the percentage of training that you have uploaded on Polar Flow from 0 – 100%?

80(1) 82.5(1) 89-90(1) 90(2) 95(2) 90-95(1) 98(1) 99(1) 98/99(1)

Any other comments:

- Remembering to do RPE information sheet, because it is at home and not by training, effects the rating put on sheet (1)
- ARSS questionnaire would be better every 2 weeks (2)
- Did not use watch properly over Easter holiday period (1)
- Watch and/or HR strap had technical failures (3)
- Support good + quick response (1)
- Questionnaires only downside – maybe different or less often (1)
- Recommend questionnaires that don’t repeat themselves (1)

- Did not record HR during trials/competition – wanted to focus on race and not worry about the watch (1)
- Would like more feedback on physiological testing (1)
- Watch not always reliable, Km not always right (1)
- Questionnaires too long (1)
- Watch can get in the way of training sometimes (1)
- RPE good to do, but difficult to remember – better for coach or cox to get when leaving the training (1)
- Needed reminders for watches at boathouse (1)
- Should get the coach more involved (1)

Appendix 11.5: ARSS Questionnaire (Kellmann and Kölling, 2018)

Name/Code	Date/Time

Acute Recovery and Stress Scale

Below there is a list of expressions that describe different states of recovery and stress. Please rate each item and mark the number that most closely applies to you **right now**.

At the moment I feel / I am ...		does not apply at all						fully applies
1	recovered	0	1	2	3	4	5	6
2	muscle exhaustion	0	1	2	3	4	5	6
3	pleased	0	1	2	3	4	5	6
4	unmotivated	0	1	2	3	4	5	6
5	attentive	0	1	2	3	4	5	6
6	feeling down	0	1	2	3	4	5	6
7	strong	0	1	2	3	4	5	6
8	tired	0	1	2	3	4	5	6
9	rested	0	1	2	3	4	5	6
10	muscle fatigue	0	1	2	3	4	5	6
11	stable	0	1	2	3	4	5	6
12	sluggish	0	1	2	3	4	5	6
13	receptive	0	1	2	3	4	5	6
14	stressed	0	1	2	3	4	5	6
15	physically capable	0	1	2	3	4	5	6
16	worn-out	0	1	2	3	4	5	6
17	muscle relaxation	0	1	2	3	4	5	6
18	unenthusiastic	0	1	2	3	4	5	6
19	in a good mood	0	1	2	3	4	5	6
20	annoyed	0	1	2	3	4	5	6
21	mentally alert	0	1	2	3	4	5	6
22	muscle soreness	0	1	2	3	4	5	6
23	energetic	0	1	2	3	4	5	6
24	overloaded	0	1	2	3	4	5	6
25	physically relaxed	0	1	2	3	4	5	6
26	muscle stiffness	0	1	2	3	4	5	6
27	having everything under control	0	1	2	3	4	5	6
28	lacking energy	0	1	2	3	4	5	6
29	concentrated	0	1	2	3	4	5	6
30	short-tempered	0	1	2	3	4	5	6
31	full of power	0	1	2	3	4	5	6
32	physically exhausted	0	1	2	3	4	5	6

Appendix 11.6: Perception of Academic Stress scale (Bedewy and Gabriel, 2015)

Appendix 1. The final version of the Perceptions of Academic Stress (PAS) scale.

Please rate your perception about the following statements in contributing to academic stresses *1 = Strongly disagree to 5 = Strongly agree*	*1*	*2*	*3*	*4*	*5*
Am confident that I will be a successful student					
Am confident that I will be a successful in my future career					
I can make academic decisions easily					
The time allocated to classes and academic work is enough					
I have enough time to relax after work					
Please rate your perception about the following statements contributing to Academic Stresses *1 = Strongly agree to 5 = Strongly disagree*	*1*	*2*	*3*	*4*	*5*
My teachers are critical of my academic performance					
I fear failing courses this year					
I think that my worry about examinations is weakness of character					
Teachers have unrealistic expectations of me					
The size of the curriculum (workload) is excessive					
I believe that the amount of work assignment is too much					
Am unable to catch up if getting behind the work					
The unrealistic expectations of my parents stresses me out					
competition with my peers for grades is quite intense					
The examination questions are usually difficult					
Examination time is short to complete the answers					
Examination times are very stressful to me out					
Even if I pass my exams, am worried about getting a job					

Appendix 11.7: RESTQ-76 (Kellmann and Kallus, 2001)

R E S T Q - 76 Sport

Single Code: ______________________ Group Code: ______________________

Name (Last): ______________________ **(First):** ______________________

Date: __________ Time: __________ Age: __________ Gender: __________

Sport/Event(s): ____

This questionnaire consists of a series of statements. These statements possibly describe your mental, emotional, or physical well-being or your activities during the past few days and nights.

Please select the answer that most accurately reflects your thoughts and activities. Indicate how often each statement was right in your case in the past days.

The statements related to performance should refer to performance during competition as well as during practice.

For each statement there are seven possible answers.

Please make your selection by marking the number corresponding to the appropriate answer.

Example:

In the past (3) days/nights

... I read a newspaper

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

In this example, the number 5 is marked. This means that you read a newspaper very often in the past three days.

Please do not leave any statements blank.

If you are unsure which answer to choose, select the one that most closely applies to you.

Please turn the page and respond to the statements in order without interruption.

In the past (3) days/nights

1) ... *I watched TV*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

2) ... *I did not get enough sleep*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

3) ... *I finished important tasks*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

4) ... *I was unable to concentrate well*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

5) ... *everything bothered me*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

6) ... *I laughed*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

7) ... *I felt physically bad*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

8) ... *I was in a bad mood*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

9) ... *I felt physically relaxed*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

10) ... *I was in good spirits*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

11) ... *I had difficulties in concentrating*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

12) ... *I worried about unresolved problems*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

In the past (3) days/nights

13) ... *I felt at ease*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

14) ... *I had a good time with friends*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

15) ... *I had a headache*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

16) ... *I was tired from work*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

17) ... *I was successful in what I did*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

18) ... *I couldn't switch my mind off*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

19) ... *I fell asleep satisfied and relaxed*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

20) ... *I felt uncomfortable*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

21) ... *I was annoyed by others*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

22) ... *I felt down*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

23) ... *I visited some close friends*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

24) ... *I felt depressed*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

In the past (3) days/nights

25) ... *I was dead tired after work*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

26) ... *other people got on my nerves*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

27) ... *I had a satisfying sleep*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

28) ... *I felt anxious or inhibited*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

29) ... *I felt physically fit*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

30) ... *I was fed up with everything*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

31) ... *I was lethargic*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

32) ... *I felt I had to perform well in front of others*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

33) ... *I had fun*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

34) ... *I was in a good mood*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

35) ... *I was overtired*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

36) ... *I slept restlessly*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

 From *Recovery-Stress Questionnaire for Athletes: User Manual* by Michael Kellmann and K. Wolfgang Kallus, 2001, Champaign, IL: Human Kinetics.

In the past (3) days/nights

37) ... *I was annoyed*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

38) ... *I felt as if I could get everything done*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

39) ... *I was upset*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

40) ... *I put off making decisions*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

41) ... *I made important decisions*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

42) ... *I felt physically exhausted*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

43) ... *I felt happy*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

44) ... *I felt under pressure*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

45) ... *everything was too much for me*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

46) ... *my sleep was interrupted easily*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	alwayss

47) ... *I felt content*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

48) ... *I was angry with someone*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

In the past (3) days/nights

49) ... *I had some good ideas*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

50) ... *parts of my body were aching*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

51) ... *I could not get rest during the breaks*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

52) ... *I was convinced I could achieve my set goals during performance*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

53) ... *I recovered well physically*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

54) ... *I felt burned out by my sport*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

55) ... *I accomplished many worthwhile things in my sport*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

56) ... *I prepared myself mentally for performance*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

57) ... *my muscles felt stiff or tense during performance*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

58) ... *I had the impression there were too few breaks*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

59) ... *I was convinced that I could achieve my performance at any time*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

60) ... *I dealt very effectively with my teammates' problems*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

In the past (3) days/nights

61) ... *I was in a good condition physically*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

62) ... *I pushed myself during performance*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

63) ... *I felt emotionally drained from performance*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

64) ... *I had muscle pain after performance*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

65) ... *I was convinced that I performed well*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

66) ... *too much was demanded of me during the breaks*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

67) ... *I psyched myself up before performance*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

68) ... *I felt that I wanted to quit my sport*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

69) ... *I felt very energetic*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

70) ... *I easily understood how my teammates felt about things*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

71) ... *I was convinced that I had trained well*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

72) ... *the breaks were not at the right times*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

In the past (3) days/nights

73) ... *I felt vulnerable to injuries*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

74) ... *I set definite goals for myself during performance*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

75) ... *my body felt strong*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

76) ... *I felt frustrated by my sport*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

77) ... *I dealt with emotional problems in my sport very calmly*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

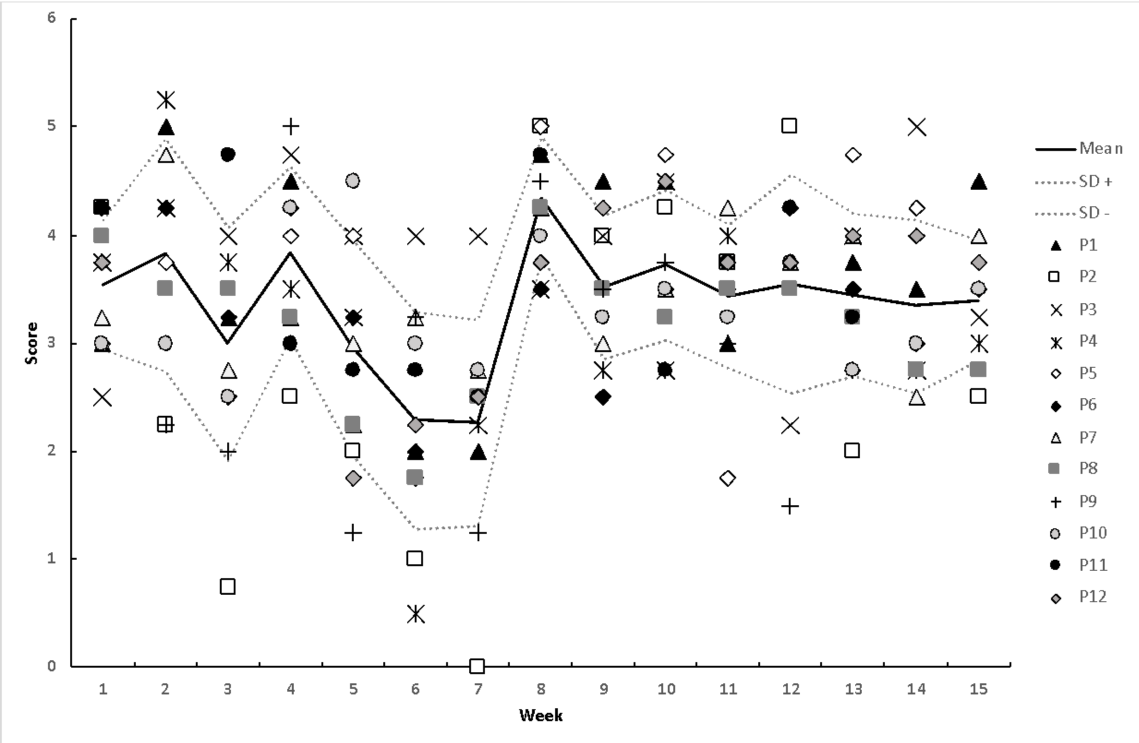
Thank you very much!

Appendix 11.8: Athlete Burnout Questionnaire (Raedeke and Smith, 2001)

Item #	Subscale	Item Text
1	RA	I'm accomplishing many worthwhile things in [*sport*]
2	E	I feel so tired from my training that I have trouble finding energy to do other things
3	D	The effort I spend in [*sport*] would be better spent doing other things
4	E	I feel overly tired from my [*sport*] participation
5	RA	I am not achieving much in [*sport*]
6	D	I don't care as much about my [*sport*] performance as I used to
7	RA	I am not performing up to my ability in [*sport*]
8	E	I feel "wiped out" from [*sport*]
9	D	I'm not into [*sport*] like I used to be
10	E	I feel physically worn out from [*sport*]
11	D	I feel less concerned about being successful in [*sport*] than I used to
12	E	I am exhausted by the mental and physical demands of [*sport*]
13	RA	It seems that no matter what I do, I don't perform as well as I should
14	RA	I feel successful at [*sport*]
15	D	I have negative feelings toward [*sport*]

Note: Response set is a 5-point Likert scale of (1) "almost never," (2) "rarely," (3) "sometimes," (4) "frequently," (5) "almost always." Items 1 and 14 are reverse-scored. RA = reduced sense of accomplishment, E = emotional/physical exhaustion, D = devaluation.

Appendix 11.9: Variation, mean and SD for ARSS Muscle Stress construct scores between participants



Appendix 11.10a: The relationships of anthropometric determinants of 2km rowing performance

Anthropometric Measure	Rowers	Test measures	Correlation	References
Height (cm)	21 M, 18 F	179.8 ± 4.1	0.76	Ingham *et al.* (2002)
	21 M	186.0 ± 4.60	0.66	
	18 F	170.3 ± 3.6	0.70	
Stroke length	21 M, 18 F	-	0.76	Ingham *et al.* (2002)
	21 M	-	0.54	
	18 F	-	0.53	
Arm length (cm)	38 M	83.86 ± 3.49	-0.70	Akça (2014)
Leg length (cm)	38 M	90.67 ± 5.88	-0.70	
Forearm girth (cm)	38 M	30.01 ± 2.51	-0.62	
Upper arm girth (cm)	38 M	29.91 ± 2.59	-0.63	
Flexed Biceps girth (cm)	38 M	33.13 ± 2.77	-0.66	
Calf girth (cm)	38 M	38.08 ± 3.02	-0.55	
Thigh girth (cm)	38 M	58.35 ± 4.25	-0.69	
Biacromial width (cm)	38 M	40.98 ± 1.77	-0.63	
Femur width (cm)	38 M	9.87 ± 0.66	-0.68	
Humerus width (cm)	38 M	7.39 ± 0.81	-0.66	
Arm span (cm)	38 M	188.44 ± 8.85	-0.72	
Body mass (kg)	21 M, 18 F	75.08 ± 4.68	0.82	Ingham *et al.* (2002)
	21 M	82.70 ± 5.40	0.76	
	18 F	67.45 ± 3.95	0.79	
Fat-free mass (kg)	21 M, 18 F	-	0.94	
	21 M	-	0.84	
	18 F	-	0.75	
Body fat (kg)	21 M, 18 F	-	-0.70	
	21 M	-	-0.68	
	18 F	-	-0.68	
Body fat percentage (%)	21 M, 18 F	16.18 ± 2.60	-0.52	
	21 M	11.70 ± 2.35	-0.48	
	18 F	20.65 ± 2.85	-0.49	

Appendix 11.10b: The relationships of aerobic capacity determinants of 2km rowing performance (Ingham *et al.*, 2002; Smith and Hopkins, 2012)

Aerobic Measure	Rowers	Test measures	Correlation	SEE (%)	90% CI	Adjusted SEE (%)	References
VO_{2max} ($L.min^{-1}$)	48 M	5.60 ± 0.56	-0.82	2.0	1.7, 2.4	2.5	Nevill *et al.* (2011)[a]
	13 M	4.5 ± 0.4	-0.85	1.4	1.0, 2.0	1.6	Cosgrove *et al.* (1999)[a]
	23 M, LW	5.05 ± 0.20	-0.70	1.3	1.0, 1.7	1.7	Bourdin *et al.* (2004)[a]
	54 M	5.41 ± 0.42	-0.84	1.8	1.5, 2.1	2.1	
	10 M, 22 F	3.62 ± 0.84	-0.96	2.5	2.1, 3.1	2.6	Gillies and Bell (2000)[a]
	22 F	3.19 ± 0.57	-0.92	2.4	1.9, 3.2	2.6	
	10 M	5.25 ± 0.69	-0.87	2.3	1.7, 3.7	2.7	Womack *et al.* (1996)[a]
	28 F, 48 M	5.02 ± 0.91	-0.94	2.7	2.4, 3.1	2.8	Nevill *et al.* (2011)[a]
	31 M, HW	5.68 ± 0.32	-0.68	2.0	1.6, 2.5	2.9	Bourdin *et al.* (2004)[a]
	21 M, 18 F	-	0.88	-	-	-	Ingham *et al.* (2002)
	21 M	-	0.82	-	-	-	
	18 F	-	0.80	-	-	-	
Gross efficiency (%)	23 M, LW	18.6 ± 0.8	-0.51	1.5	1.2, 2.0	2.7	Bourdin *et al.* (2004)[a]
Maximal power output in incremental test (W)	10 M	369 ± 37	-0.97	1.2	0.9, 1.9	1.2	Jürimäe *et al.* (2000)[a]
	54 M	422 ±37	-0.92	1.3	1.1, 1.5	1.4	Bourdin *et al.* (2004)[a]
	31 M, HWT	441 ± 34	-0.89	1.3	1.0, 1.6	1.4	

Continue on next page

Note: a – reference from Smith and Hopkins (2012). VO_{2max} – maximal oxygen consumption; SEE - standard error of estimate

Appendix 11.10b (Cont.): The relationships of aerobic capacity determinants of 2km rowing performance (Ingham *et al.*, 2002; Smith and Hopkins, 2012)

Aerobic Measure	Rowers	Test measures	Correlation	SEE (%)	90% CI	Adjusted SEE (%)	References
Maximal power output in incremental test (W)	23 M, LWT	396 ± 23	-0.76	1.2	0.9, 1.5	1.4	Bourdin *et al.* (2004)[a]
	28 F	256 ± 23	-0.92	1.6	1.3, 2.0	1.7	Nevill *et al.* (2011)[a]
	48 M	369 ± 37	-0.84	1.9	1.6, 2.3	2.3	Nevill *et al.* (2011)[a]
	28 F, 48	328 ± 64	-0.96	2.2	1.9, 2.5	2.3	
P_{VO2max}	21 M, 18 F	-	0.95	-	-	-	Ingham *et al.* (2002)
	21 M	-	0.93	-	-	-	
	18 F	-	0.91	-	-	-	

Note: a – reference from Smith and Hopkins (2012). P_{max} – maximal power; VO_{2max} – maximal oxygen consumption; P_{VO2max} – power at VO_{2max}; SEE - standard error of estimate

Appendix 11.10c: The relationships of submaximal aerobic capacity determinants of 2km rowing performance (Ingham *et al.*, 2002; Smith and Hopkins, 2012)

Measures at blood lactate	Rowers	Test measures	Correlation	SEE (%)	90% CI	Adjusted SEE (%)	References
Power at 1mmol.L^{-1} above baseline (W)	12 F	138 ± 27	-0.82	1.5	1.1, 2.3	1.8	Riechman *et al.* (2002)[a]
VO_2 at 1mmol.L^{-1} above baseline (L.min^{-1})	12 F	2.24 ± 0.36	-0.77	1.7	1.3, 2.6	2.2	Riechman *et al.* (2002)[a]
Power at lactate threshold 1	21 M, 18 F	-	0.88	-	-	-	Ingham *et al.* (2002)
	21 M	-	0.85	-	-	-	
	18 F	-	0.57	-	-	-	

Continue on next page

Note: a – reference from Smith and Hopkins (2012). Lactate infliction – aerobic/lactate threshold 1; VO_2 – oxygen consumption; SEE - standard error of estimate

Appendix 11.10c (Cont.): The relationships of submaximal aerobic capacity determinants of 2km rowing performance (Ingham *et al.*, 2002; Smith and Hopkins, 2012)

Measures at blood lactate	Rowers	Test measures	Correlation	SEE (%)	90% CI	Adjusted SEE (%)	References
VO_2 at lactate inflection ($L.min^{-1}$)	48 M	4.3 ± 0.5	-0.83	2.0	1.8, 2.5	2.4	Nevill *et al.* (2011)[a]
	21 M, 18 F	-	0.86	-	-	-	Ingham *et al.* (2002)
	21 M	-	0.82	-	-	-	
Power at 2mmol/L (W)	48 M	309 ± 36	-0.77	2.3	2.0, 2.8	2.9	Nevill *et al.* (2011)[a]
	21 M, 18 F	-	0.92	-	-	-	Ingham *et al.* (2002)
	21 M	-	0.93	-	-	-	
	18 F	-	0.92	-	-	-	
Power at 3mmol/L (W)	28 F	240 ± 24	-0.82	2.4	2.0, 3.0	2.8	Nevill *et al.* (2011)[a]
Lactate at 350 W ($mmol.L^{-1}$)	10 M	11.8 ± 4.8	0.96	1.3	0.9, 2.1	1.4	Jürimäe *et al.* (2000)[a]
Power at $4mmol.L^{-1}$ blood lactate (W)	10 M	275 ± 41	-0.96	1.3	0.9, 2.1	1.4	Jürimäe *et al.* (2000)[a]
	21 M, 18 F	-	0.92	-	-	-	Ingham *et al.* (2002)
	21 M	-	0.92	-	-	-	
	18 F	-	0.89	-	-	-	
	8 M ?	222 ± 23	0.89	1.7	1.2, 2.9	1.9	Faff *et al.* (1993)[a]
	28 F	256 ± 25	-0.84	2.2	1.8, 2.8	2.6	Nevill *et al.* (2011)[a]

Continue on next page

Note: a – reference from Smith and Hopkins (2012). Lactate infliction – aerobic/lactate threshold 1; VO_2 – oxygen consumption; VO_{2max} – maximal oxygen consumption; SEE - standard error of estimate

Appendix 11.10c (Cont.): The relationships of submaximal aerobic capacity determinants of 2km rowing performance (Ingham *et al.*, 2002; Smith and Hopkins, 2012)

Anaerobic Measure	Rowers	Test measures	Correlation	SEE (%)	90% CI	Adjusted SEE (%)	References
VO_2 at 4mmol/L blood lactate (L/min)	10 M	4.66 ± 0.75	-0.94	1.6	1.2, 2.6	1.7	Womack *et al.* (1996)[a]
	13 M	?	-0.68	2.0	1.5, 2.9	?	Cosgrove *et al.* (1999)[a]
	10 M	4.13 ± 0.63	-0.87	2.4	1.7, 3.9	2.7	Jürimäe *et al.* (2000)[a]
% VO_{2max} at 4mmol/L (%)	31 M, HWT	89.9 ± 5.2	-0.79	1.7	1.4, 2.1	2.1	Bourdin *et al.* (2004)[a]
Speed at 4mmol/L (m/min)	10 M	282 ±17	-0.93	1.7	1.2 2.7	1.9	Womack *et al.* (1996)[a]
	10 M	274 ± 18	-0.90	2.0	1.5, 3.3	2.2	Womack *et al.* (1996)[a]
Speed at 4mmol/L (m/sec)	13 M	?	-0.73	1.8	1.4, 2.7	?	Cosgrove *et al.* (1999)[a]

Appendix 11.10d: The relationships of anaerobic capacity and power determinants of 2km rowing performance (Smith and Hopkins, 2012; Akça, 2014)

Anaerobic Measure	Rowers	Test measures	Correlation	SEE (%)	90% CI	Adjusted SEE (%)	References
30 sec Wingate mean power (W)	12 F	368 ± 60	-0.87	1.3	1.0, 2.0	1.5	Riechman *et al.* (2002)[a]
	38 M	638 ± 41.80	-0.80	-	-	-	Akça (2014)
30 sec Wingate peak power (W)	12 F	380 ±63	-0.85	1.4	1.0, 2.2	1.6	Riechman *et al.* (2002)[a]
30 sec Wingate maximum power (W)	38 M	659 ± 58.11	-0.76	-	-	-	Akça (2014)

Continue on next page

Note: a – reference from Smith and Hopkins (2012). SEE - standard error of estimate

Appendix 11.10d (Cont.): The relationships of anaerobic capacity and power determinants of 2km rowing performance (Smith and Hopkins, 2012; Akça, 2014)

Power Measure	Rowers	Test measures	Correlation	SEE (%)	90% CI	Adjusted SEE (%)	References
30sec Wingate minimum power (W)	12 F	358 ±60	-0.89	1.2	0.9, 1.9	1.3	Riechman *et al.* (2002)[a]
	38 M	563 ± 57.16	-0.78	-	-	-	Akça (2014)
5-stroke all-out mean power (W)	38 M	563 ± 57.16	-0.78	-	-	-	Akça (2014)
	28 F, 48 M	523 ± 117	-0.94	2.7	2.4, 3.1	2.9	

Appendix 11.10e: The relationships of strength determinants of 2km rowing performance (Akça, 2014)

Strength Measure	Rowers	Test measures	Correlation	References
Leg press 1 RM (kg)	38 M	181.85 ± 25.55	-0.76	Akça (2014)
Bench pull 1 RM (kg)	38 M	95.90 ± 12.20	-0.75	
Biceps strength (kg)	38 M	65.66 ± 6.11	-0.72	

Appendix 11.11: GB rowing training matrix

The Training Matrix

GBROWINGTEAM

TRAINING ZONE		% HEART RATE MAX	BLOOD LACTATE (mmol/l)	STROKE RATE	% GOLD TIME	SAMPLE SESSION	Aerobic Adaptations							Anaerobic Adaptations		
CODE	NAME						Increased blood volume	Increased aerobic enzyme activity	Increased use of fatty acids as a fuel source	Improved muscle capillarisation	Increased maximum cardiac output	Increased maximum ventilatory capacity	Improved ability to use lactate as a fuel	Increased maximal rate of glycogen use	Improved muscle and blood buffering capacity	Race specific neuro-muscular adaptations
UT3	Fuel Utilisation Training	<59%	<1.0	<18	<70	>120' Low Intensity	••••	••••	••••	••••	••	•	••			•
UT2	Basic Oxygen Utilisation Training	59-67%	<2.0	18-19	70-76	70-100' Low Intensity	••••	••••	•••	••••	••	••	••	•	•	•
UT1	Oxygen Untilisation Training	67-75%	2.0 - 4.0	19-23	77-82	2-3x20-30' 4-8x8-10'	•••	••••	••	•••	•••	••	•••	••	••	••
AT	Anaerobic Threshold Training	75-85%	~4.0	24-28	82-86	2-4 x 8-10' 1-2 x 15-20' 1 x 30'	••	•••	•	•••	•••	•••	••••	•••	•••	••
TR	Oxygen Transport Training	85-100%	~4.0 - 8.0	28-36	87-95	3-6 x 3-5'	•	••		•••	••••	••••	••••	••••	••••	•••
AC	Anaerobic Capacity Training		~8.0 +	>36	>95	4-8x250m 2 4x500m 1- 2x1000m		•		••	••	••••	••	••••	••••	••••
AP	Anaerobic Power Training			>26	>95	10-20x10-15 power strokes										••••

Appendix 11.12: S&C exercise categories and weighting factors specific to the group of female rowers used in the volume load equation

Exercise category	Exercise	Weighting factor
Squat	Back squat	1
	Front squat	0.9
	Front split squat	0.9
	Goblet pause squat	0.6
Deadlift	Deadlift	1
	Romanian deadlift	0.7
	Single leg deadlift	0.6
Vertical Pull	Pull-ups	0.8
	Chin-ups	0.8
Horizontal Push	Bench Press	0.7
	Push-ups	0.7
	Dumbbell bench press	0.65
	Military press	0.6
Horizontal Pull	Bent over row	0.7
	Halsted row	0.7
	TRX	0.7
	Inverted row	0.7
	Bench pull	0.7
	Seated row	0.6
	DB row	0.6
	3-point row	0.6
	Overhead pull over	0.5
Single Leg	Forward Lunge	0.6
	Bulgarian Split squat	0.6
	DB Split squat	0.6
	Split Squat	0.6
	Reverse lunge	0.6
	SL glute raise	0.5
	Staggered stance hip thrust	0.4
Power*	Hip Thrust	0.6
	Power Clean	0.5
	Hex bar jump	0.5

*Note: * - exercises are more technique than weight focused*