Monitoring endurance athletes
A multidisciplinary approach

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The research presented in this thesis has been conducted at the School of Sport Studies, Hanze University of Applied Sciences, Groningen and Center for Human Movement Sciences, UMCG, University of Groningen.

This thesis was financially supported by:

- Science Plus Group
- NOC*NSF
- Henrike van der Does
- Inge Stoter
- Dragan Glamocic

Cover Design: Dragan Glamocic
Printed by: Ipskamp printing

**ISBN:** 978-90-367-8728-4 (printed version)
**ISBN:** 978-90-367-8727-7 (electronic version)

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Proefschrift

ter verkrijging van de graad van doctor aan de
Rijksuniversiteit Groningen
op gezag van de
rector magnificus prof. dr. E. Sterken
en volgens besluit van het College voor Promoties.

De openbare verdediging zal plaatsvinden op
woensdag 6 april 2016 om 14:30 uur

door

Tina Ardi Otter

geboren op 22 december 1986
te Voorst
Promotores
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Background
Running, cycling and rowing are sports that involve movements without a distinct beginning or ending. Most disciplines in these types of sport require a large endurance capacity of the athletes. Endurance sports are characterized by repetitive movements with a duration of more than 75 seconds for which the aerobic metabolism is of utmost importance [16,37]. If an athlete aspires to excel in any type of endurance sport, many years of training at a high volume is needed [5,17,29,43]. During these years of physical training the athlete is balancing on a thin thread in order to manage the physical stress and recovery for the improvement of performance.

Not only physical stress and recovery needs to be balanced, psychosocial stress and recovery can also influence the athletic balance [26]. The amount of psychosocial stress and recovery is dependent on the appraisal of stressful situations by the individual [46]. Examples of sources of psychosocial stress are pressure at school/work or a major life change that is negatively appraised (i.e. a negative life event) [36,46]. Examples of psychosocial recovery are having a good time with friends or feeling happy. So metaphorically speaking, the athlete who is already balancing on a thin thread needs to juggle at the same time.

In the ideal world, athletes are able to perform at their best during races. In order to do that, athletes prepare well by distributing increasing training loads over a period of time. However, in the real world, athletes do not always perform as expected. It is quite common that a disappointing performance is explained by an athlete with one or more setbacks in the athlete’s personal life. This suggests that an athlete will perform worse than usual after a (series of) stressful event(s). It is mostly retrospective anecdotal evidence that supports the notion that psychosocial stress and recovery influences performance of athletes. Yet prospective scientific evidence of this phenomenon is still scarce.

Conceptual models have been proposed in which the interaction between the athlete’s physical and psychosocial stress and recovery is related to performance [26] and injuries [1]. However, these concepts have not been studied extensively in sport practice. The total amount of stress and recovery is determined by both physical and psychosocial factors. Physical stress, physical recovery, psychosocial stress and psychosocial recovery all interact and should be carefully managed so that the improvement of performance is enabled and
the deterioration of performance and/or the occurrence of injuries are prevented. Monitoring these parameters is necessary to better understand the interactive nature of physical and psychosocial factors and the influence on performance parameters in the ongoing process. More detailed information about the parameters (i.e. physical stress, physical recovery, psychosocial stress, psychosocial recovery, performance parameters and injury parameters) will be provided further on.

A well-trained athlete, who regularly disturbs the stress-recovery balance with high physical stress (training load) and who restores the balance with sufficient recovery, will likely improve performance. This is known as “supercompensation”. If the athlete is experiencing too much stress and/or insufficient recovery, the balance changes and performance may stagnate or decrease and the athlete may be more susceptible to injuries. On the other hand, physical stress and psychosocial stress may be related as well. High training loads can cause that an athlete perceives psychosocial stress, for example when the athlete has to plan his social activities next to an already demanding training schedule. Also insufficient physical and/or psychosocial recovery in an athlete’s spare time can cause the feeling of (too) high training loads. Thus, improving athletic performance is not only characterized by a physical process, but psychosocial components should also be taken into account. Therefore, stress and recovery should be viewed from a holistic perspective (see figure 1).

For high level coaches and athletes it is important to know how training affects individual responses in performance parameters. Besides, changes in psychosocial stress and recovery could be taken into consideration when preparing and implementing a training program. This can help with the development of training programs that meet individual demands. Increased knowledge about non-training stress can help athletes to adjust physical stress (training) in relation to the total stress that is experienced [23]. Therefore, measuring and correctly interpreting physical and psychosocial stress, recovery and performance parameters on a regular basis is crucial. Figure 1 is an illustration in which the interactive nature of changes in stress, recovery and performance is emphasized.
Monitoring physical stress & recovery

Physical stress in terms of training load can be monitored by internal measures, for example, heart rate measures [3,34] or session Ratings of Perceived Exertion (sRPE) [13]. Physical stress can also be monitored by external measures, for example, distance, power output or duration [13,18]. The advantage of internal measures is that not only the current training intensity is measured but also the recovery and capacities of the athlete. For example, training at a certain power output (external load) is more demanding if the athlete trained at high intensity a few hours before (poor recovery), while the same training is less intense if the athlete is well rested (good recovery). Moreover, the same external load of a training session is more intense for an amateur athlete (low capacity) than for an elite athlete (high capacity). For accurate measurements, it is important that training load is monitored during each session [13].

Diverse findings have been published on the influence of training intensity on performance. It has been shown that low intensity training improves performance, while there was no relationship between high intensity training and performance [12]. However, it has also been stated that middle and high intensity training is related to improved performance while no relation with low intensity training was found [15]. Most studies used correlational analyses on a group-level.
which does not take individual capacities or changes into account. Therefore, there is a need to investigate the longitudinal relationships between training load and performance taking individual development into account.

There is no consensus about the best way to monitor training load and/or intensity but the combination of internal measures (heart rate and sRPE) in combination with an external measure (training duration) can provide a useful indication. Previous research has shown that the categorization of training intensity by heart rate measures and sRPE are closely related [42]. For longitudinal monitoring over multiple seasons, sRPE is the least time consuming method to collect training information and is easy to use in daily practice.

**Monitoring psychosocial stress & recovery**

Psychosocial stress and recovery are also prone to changes over time [9,22,39]. Several aspects of psychosocial stress and recovery can be monitored. Previous studies have shown that an imbalance of stress and recovery can be reflected by changes in mood state [26]. Questionnaires like Profile of Mood States (POMS) [32] focus on the symptoms of disturbed stress and recovery and Daily Analysis of Life Demands of Athletes (DALDA) [39] gives an overview of sources of stress. The recovery and stress questionnaire for athletes (RESTQ-Sport) focuses on the perception and the sources of stress and recovery [25]. It has been shown that a worsened stress and recovery state is associated with reduced performance gains [4,40], performance drop [8,9] and impaired physical recovery [31,45].

However, studies involving the RESTQ-Sport of endurance athletes generally investigated the effects of intensified training on psychosocial stress, recovery and performance, instead of investigating the interaction of changes in psychosocial stress and recovery, training parameters and performance [9,11,22,24]. Insight in changes in the perception and sources of psychosocial stress and recovery of endurance athletes and the relationship with training and performance can be helpful for coaches. This information can be taken into account when training programs are designed for the individual athlete.

**Monitoring performance parameters**

Although performance during competition is the most important parameter for an athlete, this parameter has its limitations since it is influenced by, for example,
environmental conditions [19,44] and pacing strategy [14] during the race. There is little or no consensus about standardised tests that can be performed regularly to detect changes in physical performance. The test that has been used the most in endurance sports is the incremental exercise test to determine VO$_2$max. Athletes have to run, cycle or row until exhaustion for a reliable measure of VO$_2$max. Adding tests to an already demanding training program requiring maximal effort increases the total amount of physical stress and may disturb the balance of stress and recovery of an athlete [33]. Moreover, athletes need to be highly motivated so that reliable measures of maximal performance can be obtained [2]. This may not be the case if athletes have to perform these tests frequently. Therefore, to evaluate performance parameters regularly, submaximal exercise tests could be a valid alternative. The following submaximal performance parameters have the potential to monitor endurance performance of i.e. runners, cyclists and rowers: Submaximal oxygen uptake [41], submaximal heart rate at a predetermined intensity [6] or intensity at a predetermined submaximal heart rate [28] and heart rate recovery [10]. However, not all types of endurance can be measured with a test that is readily available.

It is important to use a sport-specific test to measure submaximal performance parameters accurately. Such a test is preferably non-invasive, so that it can be incorporated into the training schedule without additional efforts. An example of a non-invasive sport-specific submaximal test is the Lamberts and Lambert Submaximal Cycle Test (LSCT) with which intensity at a predetermined submaximal heart rate and heart rate recovery can be measured. It is known that the LSCT is a reliable and valid test to monitor and predict cycling performance of male and female cyclists [28]. The design of this test is of interest because it includes multiple performance parameters and it can potentially be transferred to a rowing ergometer test and a running treadmill test.

**Monitoring injuries**

Monitoring injuries of athletes is important because an injury can be detrimental to an athletic career. The time loss because of injuries is inherent to reduced training and the inability to compete. It has been proposed that a disturbed balance between stress and recovery increases injury risk [46] (see also figure 1). Therefore, it is important to investigate the factors that can cause an increased
risk of sustaining an injury. A challenge in injury research is how to monitor and define injury. The definition of an injury impacts the injury incidence of runners [27]. In the current study, an injury was defined as any musculoskeletal problem of the lower extremity or back that led to an inability to execute training or competition as planned for at least one week [7]. It has been proposed that training errors predominantly cause overuse injuries [20,30]. In novice runners there has been some longitudinal research in which the risk of injuries was related to changes in training load [35]. However, in competitive runners training and injury data has not been collected by monitoring, but by retrospective questionnaires. These data has shown adverse results in which some authors did find a relationship between training load and injury risk [21] and some did not [38]. Therefore, monitoring athletes prospectively can add knowledge in order to prevent injuries.

**Aim & outline**

The aim of this thesis is to gain more insight into the ongoing interactions between physical stress and recovery, psychosocial stress and recovery and the influence on endurance performance parameters and injury prevalence. For that purpose we have monitored runners, cyclists, ice-skaters, triathletes and rowers for two full training seasons. Together with each coach we have created a monitoring system in which all athletes filled out a daily training log, weekly to 3 weekly RESTQ-sport questionnaires, each 6 to 7 weeks submaximal performance tests and injury registration at the time of occurrence.

**Chapter 1** explains the importance of monitoring psychosocial stress and recovery of female cyclists in relation to performance parameters. Changes in stress and recovery and the relationship with submaximal performance (intensity at a predetermined heart rate and heart rate recovery) were examined. Individual development was taken into account by using a multilevel approach.

**Chapter 2** is a special chapter because an unplanned event occurred during the monitoring period of the runners. It has been hypothesized that a negative life event has a large impact on psychosocial stress and recovery. In this chapter, the effect of this event on perceived psychosocial stress and recovery as well as submaximal performance are described.

**Chapter 3** provides insight into changes in physical stress and performance parameters of runners during an entire season. Physical stress was measured with
training intensity distribution. Running economy and submaximal HR were the measures of performance. Relationships between changes in training intensity and submaximal performance were examined by multilevel analyses in which individual differences were taken into account.

It is assumed that changes in physical stress (training load) increases injury risk. As a consequence, athletes cannot perform at their best. Therefore, in chapter 4 it is described how changes in training load, training volume and training intensity of runners influence the odds of becoming injured. Also the type, moment and severity of injuries of runners are presented.

In rowing, training regimes are exhaustive and are meant to improve performance. A new test for rowers is proposed in chapter 5 to track changes in performance without adding maximal effort to the already demanding training program. Submaximal testing of rowers offers the opportunity for future studies to investigate the influence of stress and recovery on rowing specific parameters. This chapter describes the reliability and validity of the submaximal rowing ergometer test.

The last chapter of this thesis includes a general discussion, conclusions and practical applications.

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