Summary
Periods of intensified training exert physiological and psychological stress on an athlete. If this so-called internal training load is balanced with sufficient recovery a period of intensified training results in acute fatigue (AF), characterized by increased performance capacity. Yet, increased internal training load that is not met by sufficient recovery results in a smaller increase or even reduced performance capacity. This process is termed overtraining and results in the possible outcomes functional overreaching (FOR), non-functional overreaching (NFOR), or overtraining syndrome (OTS). Besides a sub optimal effect of training (reduced or absent increase in performance), FOR has been associated with reduced sleep quality and increased risk for small illnesses. Moreover, a long-lasting stress-recovery imbalance may result in the more severe NFOR or eventually OTS, which need months to recover. Therefore, it is important to identify parameters that relate to underperformance (FOR) after intensified training. In this thesis we focused on some of the most promising parameters, namely hormones, heart rate, reaction time and monitoring of stressors and symptoms of overtraining.

The Tour for Life (TFL), an 8-day non-competitive amateur cycling event that was the ecological source of this thesis, was applied as an experimental model. This TFL model was used to investigate whether hormonal levels, heart rate, reaction time or monitoring of stressors and symptoms can be used to distinguish between acute fatigue and functional overreaching. We defined the AF group as the group with no performance decrement and the FOR group as the group that underperformed after the TFL.

In chapter 2 it was investigated whether ACTH, cortisol, growth hormone, prolactin, metanephrine and normetanephrine levels were altered during the TFL. It was hypothesized that hormonal levels would change in FOR athletes, but not or to lesser extent in AF athletes. Blood samples were drawn in the afternoon immediately after the stage and the following morning at the start, halfway and end of the TFL. Overnight urine samples were collected the same mornings. None of the hormonal levels at the start, halfway and the end of the TFL were different between AF and FOR (all P> .20). On total group level
Summary
(AF+FOR), afternoon cortisol (P<.01) and growth hormone (P<.001) were increased from the start of the TFL. Morning ACTH, cortisol and prolactin decreased, whereas GH increased during the TFL (all P<.001). Metanephrine and normetanephrine levels did not change significantly (both P=.08). The change in growth hormone levels from the start to the end of the TFL were most strongly associated with the change in performance (afternoon: $r=-.68$, morning: $r=-.63$). This might point towards a relation between energy balance and change in performance.

Because it has been suggested that stimulation tests are more suitable than resting levels to demonstrate hormonal disturbances in the overtraining spectrum, a laboratory Two Bout Exercise Protocol has been applied in chapter 3. It was hypothesized that in FOR athletes 1) resting levels of ACTH, cortisol, GH and PRL would remain unchanged 1 and 5 weeks after the TFL, 2) exercise-induced hormonal responses would be reduced, most pronounced after the second exercise bout on a day, and 3) these changes would be absent or less noticeable in AF athletes. Two weeks before (pre TFL), 1 week after (post TFL) and 5 weeks after (follow-up) the TFL, subjects performed a maximal incremental cycling test in the morning and afternoon. Blood was drawn before and after each test and analysed for ACTH, cortisol, growth hormone and prolactin. It was shown that resting ACTH (P<.01) and GH (P<.001) were higher pre than post TFL. The response to the morning test was higher pre than post TFL for ACTH (P=.02), cortisol (P<.001) and PRL (P<.01), but not for GH (P=.12). The response to the afternoon test was only for cortisol higher pre than post TFL (P<.001). The results of the studies presented in chapter 2 and 3 clearly demonstrated a down-regulation of the hormonal system already in the early stages of the training-overtraining spectrum. Yet, the changes in the hormonal system were not different between AF and FOR athletes. This suggests that a down-regulation of the hormonal system is not the (single) performance limiting factor in FOR athletes.

Heart rate is often used to prescribe and monitor intensified training. However, it is unknown whether the change in heart rate is associated with the result of
intensified training, i.e. with the change in physical performance. In chapter 4 we evaluated cardiopulmonary exercise tests before and after the TFL. It was hypothesized that (sub) maximal heart rate would be lower after the TFL, but that this decrease would not be associated with a change in performance. In line with our hypothesis, post TFL heart rate was significantly reduced at low (-4.4 beats·min\(^{-1}\), 95% CI [-8.7, -0.1]) and medium (-5.5 beats·min\(^{-1}\) [-8.5, -2.4]), but not at high intensity. Also peak heart rate was 3.4 beats·min\(^{-1}\) [-6.1, -0.7] lower post compared to pre TFL. In contrast, no changes in \(\dot{V}O_2\) (P=.44) or the ventilator threshold (P=.21) were observed. Possibly, the decreased heart rate was compensated by an increased stroke volume or arteriovenous oxygen difference, as indicated by an increased \(O_2\) pulse (0.49 ml O\(_2\)·beat\(^{-1}\) [0.09, 0.89]). No differences between FOR and AF were observed for heart rate (P=.51). These results of this chapter suggest that heart rate is inadequate to prescribe and monitoring intensified training.

In chapter 5 we investigated whether choice reaction time can be used as a monitoring tool to establish overreaching. Reaction time has been suggested to be a practical monitoring tool that can easily be implemented in sports practice. Yet, until now, the limited available data is ambiguous. Our results showed that reaction time at the end of the TFL was 68 ms (95% CI [46, 89]) faster than at the start. During the laboratory assessments, reaction time post TFL (41 ms, 95% CI [12, 71]) and at follow-up (55 ms, 95% CI [26, 83]) were faster than pre TFL. The time by class interaction was not significant during (P=.26) and after (P=.43) the TFL. Also, correlations between physical performance and reaction time were not significant (all P>.30). It was, therefore, concluded that choice reaction time is likely not a useful tool to distinguish between AF and FOR.

In chapter 6 we combined the Rating of Perceived Exertion, items from a validated online training monitor system, the Profile of Mood States questionnaire (POMS), resting heart rate and rectal temperature to study which (combination of) parameters can be used to early distinguish between AF and FOR. These easily measurable stressors and symptoms were
monitored during the TFL. The combination of subjective rating of fatigue and readiness to train on visual analogue scales (VAS) were most powerful to distinguish between AF and FOR. After three days cycling these 2 parameters correctly predicted 78% of the subjects as AF or FOR (sensitivity=79%, specificity=77%).

In chapter 7 it was concluded that we did not identify a single performance-limiting factor in amateur cyclists after an 8-day non-competitive event. Instead, monitoring of the stress-recovery balance (which reflects the underlying process of the overtraining spectrum) by means of subjective ratings of fatigue and readiness to train was shown most powerful to distinguish between AF and FOR. Practitioners are, therefore, encouraged to incorporate frequent monitoring of the stress-recovery balance in supervision of their athletes. They are advised to adapt their methodology so that it best fits the situation and desires of the athletes and coaches.