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Human Kinetics
BRIEF REVIEW

A Systematic Review on Markers of Functional Overreaching in Endurance Athletes

Annemiek J. Roete, Marije T. Elferink-Gemser, Ruby T.A. Otter, Inge K. Stoter, and Robert P. Lamberts

Purpose: The aim of this brief review was to present an overview of noninvasive markers in trained to professional endurance athletes that can reflect a state of functional overreaching. ***Methods:*** A systematic literature search was conducted in the PubMed, Scopus, and PsycINFO databases. After screening 380 articles, 12 research papers were included for the systematic review. ***Results***: Good consensus was found between the different papers in which noninvasive parameters were able to reflect a state of functional overreaching. Changes in power output (PO), heart rate (HR; [sub]maximal and HR recovery), rating of perceived exertion, and scores in the Daily Analysis of Life Demands for Athletes (DALDA) and/or Profile of Mood States (POMS) were shown to be able to reflect functional overreaching, whereas changes in maximal oxygen uptake and HR-variability parameters were not. ***Conclusion:*** Functional overreaching within a maximal performance test was characterized by a decrease in peak PO and a lower maximum HR, whereas a lower mean PO and a lower HR were observed during time trials. Changes in parameters during a standardized submaximal test when functionally overreached were characterized by a higher PO at a fixed HR or a lower HR at a fixed intensity, higher rating of perceived exertion, and a faster HR recovery. Although both the DALDA and POMS were able to reflect functional overreaching, the POMS was not able to differentiate this response from acute fatigue, which makes it unsuitable for accurately monitoring functional overreaching.

Keywords: monitoring, fatigue, cycling, running, triathlon, training prescription

Athletes aim to improve their performance through finding the optimal balance between training load and recovery.[1,2] As the best gains in training response are generally achieved with high training load and the minimal but appropriate recovery time, athletes tend to balance on this fine line between doing right and doing too much.[1,3,4] An effective training session is based not only on the applied training stimulus but also on the recovery response to this stimulus.[5,6] However, this response to training might vary substantially from athlete to athlete as the rate of recovery is influenced by the physiological and nutritional status as well as the emotional balance and illnesses or injuries the athlete needs to deal with.[3,7,8] Therefore, monitoring the recovery status from training and, with this, trying to quantify the state of fatigue is very important.

Monitoring fatigue is complex as fatigue is a multifaceted phenomenon with multiple definitions, making its precise measurement difficult.[9] Fatigue is frequently used as a positive subjective marker of a training session as most sessions aim to apply an overload stimulus. In other words, experiencing fatigue is part of training and is frequently used as a subjective assessor by an athlete to determine whether or not he or she has trained “sufficiently.” or not. As acute fatigue is generally part of the overload stimulus given to achieve an improvement in training status,[4] fatigue is not, per definition, considered as a negative response. However, if fatigue accumulates and an athlete is not able to recover from a training stimulus, he or she can develop a state of functional overreaching, nonfunctional overreaching, or even a full-blown overtraining syndrome.[4]

Although an athlete, in most cases, recovers from a training session within 24 to 72 hours, the recovery from a functional overreaching status generally takes about 5 to 7 days.[4] As the term “functional” already implies, overreaching to a certain extent, which is followed by an extended period of recovery to allow the body to supercompensate, has proven to be an effective training regimen,[5] and is commonly a target of a training camp.[10] Substantially longer recovery periods are associated with nonfunctional overreaching (weeks to months) and a full-blown overtraining syndrome (months to up to more than a year).[4] As the latter 2 stages are associated with long-term adverse effects on performance, it is extremely important to be able to recognize symptoms of functional overreaching from which athletes can recover relatively quickly and prevent the development of a nonfunctional overreaching status. Although this is important for all athletes, endurance athletes with high training loads[11,12] seem to be at higher risk of developing a nonfunctional overreaching status. As athletes tend to regularly use training techniques in which they aim to functionally overreach themselves, the risk of developing a nonfunctional overreaching status is relatively high.

Although several papers have studied the effects of functional overreaching on noninvasive parameters, no systematic review to date has provided an overview of which noninvasive markers are able to reflect a state of functional overreaching and how much consensus there is between the different studies. Therefore, the aim of this systematic review is to provide an overview of which noninvasive fatigue markers are able to reflect a state of functional overreaching in trained to professional endurance athletes.

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Methods

Data Sources

An electronic literature search was performed in the digital databases of PubMed, Scopus, and PsycINFO. The used search terms were "monitoring" AND "fatigue" OR "fatigue" OR "overreaching" AND "athletes" ((monitoring [All Fields] AND ("fatigue" [MeSH Terms] OR "fatigue" [All Fields]) OR overreaching [All Fields] AND ("athletes" [MeSH Terms] OR "athletes" [All Fields])) AND English [Language]). In addition, the articles had to be in the English language, in peer-reviewed scientific journals, and published between January 2010 and January 2020. This search yielded 309 articles from PubMed and Scopus and 93 articles from PsycINFO (see Figure 1).

Study Selection: Inclusion and Exclusion Criteria

After the duplicates were removed, the titles and abstracts of the articles were read independently by 2 of the authors (A.J.R. and R.P.L.). Inclusion criteria for the systematic review were: (1) studies that had used an overload training load model to induce functional overreaching, (2) studies focusing on trained to professional athletes (based on performance level 3–5 as defined by De Pauw et al[13] for men and Decroix et al[14] for women), (3) focused on noninvasive markers reflecting functional overreaching and, (4) athletes displayed minimally 2 of the 3 indicators of being functionally overreached. To determine whether athletes were, indeed, functionally overreached, the following indicators were used: (1) a decrease in performance,[4] (2) increased rating of perceived exertion (RPE) at the same intensity,[2] and (3) subjective indicators of increased stress or fatigue levels.[1,15,16] In addition, changes in performance parameters after a taper period and/or the duration of the overload period were assessed to confirm the state of functional overreaching.

After the initial online search, 373 abstracts were screened for eligibility (see also Figure 1). Upon screening the abstracts, 40 full-text articles were downloaded and screened in detail for the inclusion criteria, as mentioned earlier. Based on the strict criteria, 12 articles were included as part of the current systematic review. Screening of the abstracts and articles was done independently by A.J.R. and R.P.L. Articles marked as "unsure of meeting the inclusion criteria" or where there was a discrepancy between recommending it to be "included" or "excluded" were discussed in detail, after which a consensus was reached. The quality of the included papers was assessed independently by A.J.R. and R.P.L. and based on the level of evidence of the Oxford Centre for Evidence-Based Medicine.[17] The Oxford Centre for Evidence-Based Medicine scale ranges from level 1a, reflecting a systematic review of high-quality randomized controlled trials, to level 5, reflecting an expert opinion.

Responses in parameters to a state of functional overreaching were grouped as responses in "physiological parameters," in "heart rate parameters," and in "subjective parameters." Changes in parameters were based on a significance ($P < .05$), not based on the likelihood that a change would be clinically relevant and not based on Cohen effect sizes. If the change was significant, the amount of change in the parameter was expressed by the weighted average, calculated as the percentage change per study multiplied by the number of participants per study, which was then summated for the same parameters and divided by the sum of participants of those studies. As recommended,[2] data from stage 1 of both the

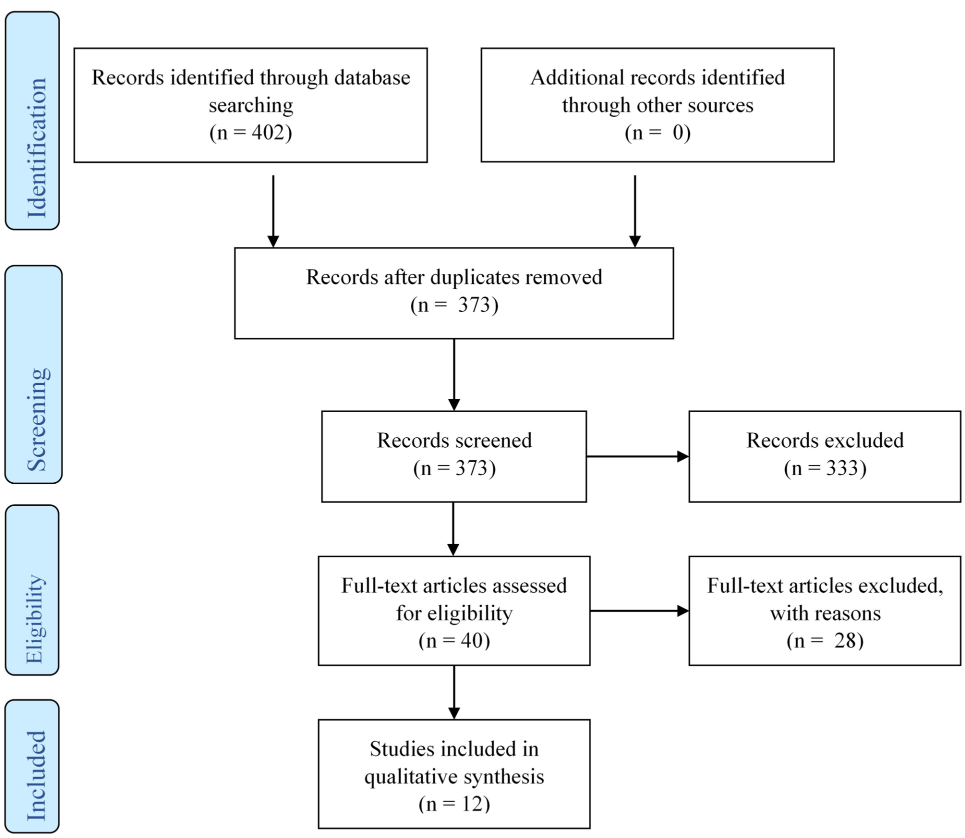

Figure 1 — Flowchart of study selection in the systematic review.

Lamberts submaximal cycle test (LSCT) and Lamberts submaximal running test (LSRT) were not included as part of the systematic review based on the relatively high variability in these parameters at this intensity.

Results

The characteristics of the included studies are summarized in Table 1. The level of evidence, based on the Oxford Centre for Evidence-Based Medicine ranking system, ranged from 1b (5 papers) to 2b (6 papers), whereas 1 paper was quantified as level 3b (see also Table 1). Six of the 12 included papers (50%) had a control group that was either not fatigued (n = 3) or acutely fatigued (n = 3) instead of functionally overreached. The average number of participants per study was 11 (6) and ranged from 1 to 23 participants. In total, 136 participants within 12 different studies were included in this systematic review. Participants of the studies were of a weighted average of 33 years with the average age ranging from 24 to 38 years. The studies focused on cyclists (n = 5 [42%]), triathletes (n = 4 [33%]), long-distance runners (n = 1 [8%]), a combination of cyclists and triathletes (n = 1 [8%]), or on a combination of runners, cyclists, and triathletes (n = 1 [8%]). The average training status per paper varied from "trained (n = 5 [42%])" to "well-trained" (n = 4 [33%]) and to professional (n = 3 [25%]). The mean overload of the interventions was 188% (99%) and ranged from 130% to 513% of normal training load. Only one study, by Hammes et al,[18] did not quantify the level of overload. All studies met at least 2 of the 3 indicators of being functionally overreached, whereas 10 studies also confirmed the functional overreaching status by showing a temporary performance decrease that improved again after a taper period.

Physiological Parameters

An overview of the physiological responses to functional overreaching are shown in Table 2.

Five studies examined changes in VO_2max during cycling or running caused by the overload period.[18–22]

Seven cycling studies examined the change in power output (PO) before and after the overload period. Changes in peak power output (PPO) were studied in 4 papers,[18,19,21,23] whereas mean PO during a time trial (TT) was studied in 3 papers.[18,24,25] Submaximal PO while cycling at a fixed heart rate (HR) was also studied in 3 papers.[10,18,26]

HR Parameters

The overview of HR responses to functional overreaching are shown in Table 3.

Ten studies examined a measure of HR and its change after the period of overload. Three of the studies examined resting

Table 1 Characteristics of the Included Studies

Study	Study design (evidence level)	N (sex) [status]	Training status	Sport(s)	Fatigue protocol
Lamberts et al[26]	Case study (3b)	1 (M) [FO]	Professional	Cycling	233% (1 wk) and 160% (1 wk) of normal training load
Le Meur et al[20]	Randomized controlled trial (1b)	8 (M) [C] 13 (M) [FO]	Trained to well-trained	Triathlon	3 wk—140% of normal weekly training load
Dupuy et al[22]	Cross-sectional (2b)	11 (M) [FO]	Trained	Cycling, triathlon, and running	2 wk—200% of normal weekly training load
Le Meur et al[19]	Randomized controlled trial (1b)	11 (M) [C] 12 (M) [AF] 12 (M) [FO]	Trained	Triathlon	3 wk—130% of normal weekly training load
Aubry et al[23]	Randomized controlled trial (1b)	10 (M) [C] 11 (M) [AF] 10 (M) [FO]	Trained to well-trained	Triathlon	3 wk—130% of normal weekly training load
Decroix et al[24]	Cross-sectional (2b)	4 (F) [AF] 5 (F) [FO]	Professional	Cycling	8-d training camp—149% of normal training load
Hammes et al[18]	Cross-sectional (2b)	23 (M) [FO]	Trained	Cycling and triathlon	6 d of high-intensity and high-volume training[a]
Le Meur et al[28]	Randomized controlled trial (1b)	8 (M) [C] 13 (M) [FO]	Trained	Triathlon	3 wk—140% of normal weekly training load
Siegl et al[27]	Cross-sectional (2b)	11 (M) and 3 (F) [FO]	Trained to well-trained	Running	56-km ultramarathon—513% of normal daily training load
Coates et al[21]	Randomized controlled trial (1b)	8 (M) and 5 (F) [C]; 8 (M) and 7 (F) [FO]	Trained	Cycling and triathlon	3 wk—150% of normal weekly training load
Decroix et al[10]	Cross-sectional (2b)	6 (F) [FO]	Professional	Cycling	8-d training camp—208% of normal weekly training load
Woods et al[25]	Cross-sectional (2b)	13 (M) [FO]	Trained to well-trained	Cycling	2 wk—144% of normal weekly training load

Abbreviations: AF, acute fatigue; C, control group; F, female; FO, functional overreaching; M, male.
[a] Percentage overload compared to the normal weekly training was not quantified.

Table 2 Overview of Physiological Responses to Functional Overreaching

Variable	Duration	Change	Reference
VO_2max			
Maximal			
Max cycle test			
VO_2max during max PPO test	Max test	↓	Le Meur et al[19]
VO_2max during max PPO test	Max test	↔	Hammes et al[18]
VO_2max during max PPO test	Max test	↔	Coates et al[21]
Max running test			
VO_2max during max PTRS test	Max test	↔	Dupuy et al[22]
PO			
Submaximal			
@80% HR_{max}			
PO at 80% HR_{max} (LSCT)	6 min	↑	Lamberts et al[26]
PO at 80% HR_{max} (LSCT)	6 min	↑	Hammes et al[18]
PO at 80% HR_{max} (LSCT)	6 min	↑	Decroix et al[10]
@90% HR_{max}			
PO at 90% HR_{max} (LSCT)	3 min	↔ (↑[b])	Lamberts et al[26]
PO at 90% HR_{max} (LSCT)	3 min	↑	Hammes et al[18]
PO at 90% HR_{max} (LSCT)	3 min	↔ (↑[a])	Decroix et al[10]
TT			
Mean PO during 30-min TT	30 min	↓	Decroix et al[24]
Mean PO during 40-km TT	±65 min	↓	Hammes et al[18]
Mean PO during 4-km TT	±5 min	↓	Woods et al[25]
Maximal			
PPO			
PPO	Max test	↓	Le Meur et al[19]
PPO	Max test	↓	Aubry et al[23]
PPO	Max test	↔	Hammes et al[18]
PPO	Max test	↓	Coates et al[21]

Abbreviations: HR, heart rate; LSCT, Lambert submaximal cycle test; PO, power output; PPO, peak power output as part of a maximal cycling test; PTRS, peak treadmill running speed as part of a maximal running test; TT, time trial.
[a] Tendency. [b] Initial first minute was higher but following 2 minutes the same.

HR.[20,21,26] Nine studies examined the highest attained HR before and after the overload period, of which 3 examined the change at submaximal intensities[24,25,27] and 6 at maximal intensities.[18–23]

Six studies examined the change in HR recovery over 60 seconds and 4 studies assessed HRR after submaximal exercise[18,26–28] and 3 after maximal exercise.[21,23,28] Four studies examined a domain measure of heart rate variability (HRV). All 4 of those studies examined the root mean square of successive differences of the R–R intervals domain.[20–22,25] Two studies examined the mean of the SDs of all the normal-to-normal intervals,[21,22] and 3 examined the low-/high-frequency ratio.[20–22]

Subjective Parameters

An overview of the responses found in subjective rating markers is shown in Table 4.

Seven studies assessed the RPE after the period of overload in comparison with before the overload period. Four of those studies examined RPE at submaximal intensities during LSCT and/or LSRT tests,[10,18,26,27] and 3 of the studies examined RPE at a maximal intensity while running.[20,22,28]

Two studies examined the change in Daily Analysis of Life Demands for Athletes (DALDA) before and after the overload period.[26,27]

Five studies examined the Profile of Mood States (POMS) questionnaires or subscales of the POMS questionnaire, from which 2 studies examined the fatigue mood state,[19,23] 2 examined the energy index,[22,24] and 1 examined the total score of the POMS-2.[21]

Discussion

An extensive literature search yielded 380 scientific articles; however, only 12 studies matched the strict selection criteria of focusing on "trained to professional endurance athletes" and studying "noninvasive markers of functional overreaching." Although the strict criteria limited the number of studies that were included for this systematic review, it allowed us to compare the studies and provide the reader with an overview of noninvasive markers that are able to reflect a state of functional overreaching. In addition, this systematic review provides valuable insight into how high the level of agreement is for the different noninvasive markers that can reflect a state of functional overreaching. All papers quantified the percentage of overload except

Table 3 Overview of HR Responses to Functional Overreaching

Variable	Duration	Change	Reference
HR			
Resting HR			
HR_{rest} supine—after waking up[a]	At wake-up	↔	Lamberts et al[26]
HR_{rest} supine—after exercise[a]	After 4 min	↔	Le Meur et al[20]
HR_{rest} supine—before exercise[a]	After 5 min	↔	Coates et al[21]
Submax HR			
HR at 86% HR_{max} (LSRT)	6 min	↓	Siegl et al[27]
HR at 95% HR_{max} (LSRT)	3 min	↓	Siegl et al[27]
TT			
Mean HR during 30-min TT	30 min	↓	Decroix et al[24]
Mean HR during 4-km TT	±5 min	↓	Woods et al[25]
Max HR			
Max cycle test			
HR_{max} during max PPO test	Max test	↓	Le Meur et al[19]
HR_{max} during max PPO test	Max test	↓	Aubry et al[23]
HR_{max} during max PPO test	Max test	↓	Hammes et al[18]
HR_{max} during max PPO test	Max test	↓	Coates et al[21]
Max running test			
HR_{max} during max PTrRS test	Max test	↓	Le Meur et al[20]
HR_{max} during max PTRS test	Max test	↓	Dupuy et al[22]
HRR			
After submaximal intensity			
HRR after LSCT (90% HR_{max})	60 s	↑	Lamberts et al[26]
HRR after LSCT (90% HR_{max})	60 s	↔(↑[b])	Hammes et al[18]
HRR during PTrRS test (61%–100%)	60 s	↑	Le Meur et al[28]
HRR after LSRT (95% HR_{max})	60 s	↑	Siegl et al[27]
After maximal intensity			
HRR after max test	60 s	↑	Aubry et al[23]
HRR after max test	60 s	↑	Le Meur et al[28]
HRR after max test	60 s	↑	Coates et al[21]
HRV			
Time domain			
RMSSD			
Ln RMSSD—supine—after week 1[a]	At wake-up	↔	Le Meur et al[20]
Ln RMSSD—supine—after week 2[a]	At wake-up	↔	Le Meur et al[20]
Ln RMSSD—supine—after week 3[a]	At wake-up	↔	Le Meur et al[20]
Ln RMSSD—standing—after week 1[a]	At wake-up + 8 min	↔	Le Meur et al[20]
Ln RMSSD—standing—after week 2[a]	At wake-up + 8 min	↔	Le Meur et al[20]
Ln RMSSD—standing—after week 3[a]	At wake-up + 8 min	↔	Le Meur et al[20]
Ln RMSSD—supine	After ≥ 5 min	↓	Woods et al[25]
RMSSD—during Stroop task	During stroop test	↔	Dupuy et al[22]
RMSSD—supine—before exercise	After ≥ 5 min	↔	Coates et al[21]
SDNN			
SDNN—before exercise	After ≥ 5 min	↔	Coates et al[21]
SDNN—during Stroop task	During stroop test	↔	Dupuy et al[22]
Frequency domain			
LF/HF ratio			
LF/HF—supine—after week 1[a]	At wake-up	↔	Le Meur et al[20]
LF/HF supine—after week 2[a]	At wake-up	↔	Le Meur et al[20]
LF/HF supine—after week 3[a]	At wake-up	↔	Le Meur et al[20]

(continued)

Table 3 (continued)

Variable	Duration	Change	Reference
LF/HF standing—after week 1[a]	At wake-up + 8 min	↔	Le Meur et al[20]
LF/HF standing—after week 2[a]	At wake-up + 8 min	↔	Le Meur et al[20]
LF/HF standing—after week 3[a]	At wake-up + 8 min	↔	Le Meur et al[20]
LF/HF—during stroop test	During stroop test	↔	Dupuy et al[22]
LF/HF—before exercise	After ≥ 5 min	↔	Coates et al[21]

Abbreviations: HR, heart rate; HRR, HR recovery; HRV, HR variability; LF/HF, low- to high-frequency ratio; LSCT, Lambert submaximal cycle test; PPO, peak power output as part of a maximal cycling test; PTrRS, peak track running speed; PTRS, peak treadmill running speed as part of a maximal running test; RMSSD, root mean square of successive differences of the R–R intervals; SDNN, SD of normal-to-normal intervals; TT, time trial.
[a] Isolated daily values. [b] Change was reported to be clinically relevant.

Table 4 Overview of Subjective Rating Markers (RPE, DALDA, and POMS) to Functional Overreaching

Variable	Duration	Change	Reference
RPE			
@ 80% HR_{max}			
RPE at 80% HR_{max}	6 min	↑	Lamberts et al[26]
RPE at 80% HR_{max}	6 min	↑	Hammes et al[18]
RPE at 80% HR_{max}	6 min	↑	Decroix et al[10]
@ 90% HR_{max}			
RPE at 90% HR_{max}	3 min	↑	Lamberts et al[26]
RPE at 90% HR_{max}	3 min	↑	Hammes et al[18]
RPE at 90% HR_{max}	3 min	↑	Decroix et al[10]
@ 70% PTRS			
RPE at 86% HR_{max}	6 min	↔	Siegl et al[27]
@ 85% PTRS			
RPE at 95% HR_{max}	3 min	↑	Siegl et al[27]
RPE at PTrRS	Max test	↔	Le Meur et al[20]
@ 100% PTRS			
RPE at PTRS	Max test	↔	Dupuy et al[22]
RPE at PTrRS	Max test	↑	Le Meur et al[28]
DALDA			
DALDA	90–120 s	↑ (part B)	Lamberts et al[26]
DALDA	90–120 s	↑ (part B)	Siegl et al[27]
POMS			
Fatigue subscale			
POMS (65)—before testing	5–15 min	↑	Le Meur et al[19]
POMS (65)—before testing	5–15 min	↑	Aubry et al[23]
Energy index			
POMS (65)—before testing	5–15 min	↓	Dupuy et al[22]
POMS (32)—before testing	2–8 min	↓	Decroix et al[24]
Total score			
POMS-2 (65)—after testing	5–15 min	↑	Coates et al[21]

Abbreviations: DALDA, Daily Analysis of Life Demands for Athletes; POMS, Profile of Mood States; HR, heart rate; PTrRS, peak track running speed; PTRS, peak treadmill running speed as part of a maximal running test; RPE, rating of perceived exertion.

for the study by Hammes et al,[18] which makes interpreting the findings of this study slightly more difficult.

Physiological Parameters

VO_2max. VO_{2max} was studied in 4 papers, of which 1 was determined during a maximal incremental running test and 3 were captured as part of a maximal cycling test. Of the 4 studies, 3 showed no change, and only 1 study reported a significantly lower VO_2max value.[20] The absence of change in VO_2max indicates that this noninvasive marker has a low sensitivity to reflect a state functional overreaching. The low sensitivity can partially be explained by a relatively high associated measurement error (1.9%–2.7%) of VO_2max.[29] In addition, multiple studies have shown that although a high VO_2max is important for endurance athletes, the predictive value of VO_2max to predict performance of well-trained endurance athletes is limited.[30]

Power Output. Changes in cycling PO as a marker of functional overreaching were studied in 7 papers. Of these 7 papers, 4 studied PPO, 3 studies studied mean PO during a TT, and 3 studies examined submaximal PO at a fixed HR. Three of the 4 papers that looked at PPO showed a decrease in PPO when athletes were functionally overreached.[19,21,28] In contrast, Hammes et al[18] reported no significant change in PPO but did indicate that the "lower" PPO had an 86% likelihood of being clinically relevant. In line with lower PPO, Woods et al[25] reported lower cycling sprints POs over 15 seconds with a state of functional overreaching. The mean weighted average decrease in PPO in the studies was 2.8% in athletes who were functionally overreached. Two studies that also studied athletes with "acute fatigue" reported conflicting PPO findings (no change in PPO[19]; increase in PPO[23]), whereas in the control groups no changes in PPO were observed.[19,23]

All 3 papers studying changes in TT performance reported a lower mean PO when being functionally overreached.[18,24,25] The average weighted decrease in mean PO was 4.4%. However, this percentage needs to be interpreted with care as the TT distance within the different studies varied from 4 to 40 km. In further support, Decroix et al[24] showed that in contrast to the functionally overreached athletes, athletes with acute fatigue had no change in mean PO during the TT.

Studies looking at submaximal PO when riding at a fixed HR showed to be higher in all of 3 studies when cycling at 80% HR_{max},[10,18,26] whereas 1 study[18] also showed this when riding at 90% of HR_{max}, and 2 other papers[10,26] showed a tendency of being higher with being functionally overreached. The submaximal intensities showed a weighted increase of 15.5% at 80% HR_{max} and 5.8% at 90% of HR_{max}.

HR Parameters. All included studies examined HR-derived markers of functional overreaching, which ranged from resting, submaximal, and maximal HR to HR recovery and HR variability.

All 3 papers that examined resting HR[20,21,26] showed that resting HR does not change with a state of functional overreaching in endurance athletes. One study by Le Meur et al[20] showed a slight decrease in resting HR in week 2 but only when resting HRs of a week were averaged, whereas daily changes in resting HR were nonsignificant.

Changes in submaximal HR as a marker of functional overreaching was investigated in 3 papers. Two papers studied changes in submaximal HR during a TT,[24,25] which showed, on average, a 3.3% weighted decrease of the mean HR. In addition, Decroix et al[24] reported that in contrast to the functionally overreached athletes, no changes in submaximal HR values were found in athletes with acute fatigue.

In line with the TT paper, Siegl et al,[27] who studied changes in submaximal HR when running at a fixed speed, also reported lower submaximal HR (2.4%–3.4%) in athletes who were functionally overreached.[27] This finding suggests that the decrease in HR in the TT can likely not be all contributed to the lower mean PO that was also reported in these studies.

The findings of Siegl et al,[27] who used a fixed submaximal intensity protocol (LSRT), are in line with the fixed HR-based submaximal studies (LSCT) of Lamberts et al,[26] Hammes et al,[18] and Decroix et al.[10] Whereas Siegl et al[27] reports a lower submaximal HR at the same intensity, Lamberts et al,[26] Hammes et al,[18] and Decroix et al[10] all report increased PO at the same submaximal HR, which is physiologically correct and in line with each other.

Maximal HR was studied in 6 papers. In 4 studies, HR_{max} was determined based on a maximal cycle test,[18,19,21,28] whereas the HR_{max} in 2 other studies was determined based on a maximal running test.[20,22] In line with the submaximal HR findings, maximal HR also decreased with functional overreaching in all studies. The overall observed weighted decrease in HR_{max} with functional overreaching was 5.2%. In further support and in contrast to the athletes who were functionally overreached, 2 studies showed no change in HR_{max} in athletes with acute fatigue,[19,23] whereas 4 studies showed no change in the athletes in the control group.[19–21,23]

Seven studies examined the sensitivity of HRR as a marker for functional overreaching. Four papers studied changes in HRR after a fixed submaximal intensity,[18,26–28] and 3 studies looked at HRR after a maximal performance test. In total, 6 of the 7 studies reported a faster HRR with functional overreaching. The study by Hammes et al[18] reported a 91% likelihood that the mean increase of 8 beats (range from 2 to 14) was clinically relevant; however, this was not reported as being significantly higher. Nonetheless, overall, a faster HRR after high submaximal or maximal intensity seems to be a sensitive marker of functional overreaching with an average weighted observed change of 13.7%. In contrast to functionally overreached athletes, 1 study reported no change in HRR in athletes with acute fatigue,[23] whereas 3 studies reported no change in HRR in their control group.[21,23,28]

Changes in HRV as a marker of functional overreaching were studied in 5 papers.[20–22,25] Within the time domain, (ln) root mean square of successive differences of the R–R intervals was most commonly studied, whereas 2 papers also looked at SD of normal-to-normal intervals. Within the frequency domain, low-frequency, high-frequency, and the low-/high-frequency ratio were most commonly studied. In contrast to HRR, HRV showed no change with a state of functional overreaching in all studies except for Woods et al,[25] who reported a decrease ln root mean square of successive differences of the R–R intervals values. However, the overall findings of this systematic review indicate that HRV markers do not seem to be sensitive enough to reflect a state of functional overreaching.

Subjective Parameters

Rating of Perceived Exertion. RPE was studied in 7 papers, of which 4 studies looked at changes in RPE at submaximal intensity,[10,18,26,27] and 3 papers looked at changes in RPE at termination of a maximal running test.[20,22,28]

Submaximal RPE while cycling at 80% and 90% of HR_{max} increased with functional overreaching in all 3 LSCT studies.[10,18,26] In line with this, Siegl et al[27] showed an increased RPE with functional overreaching while running at 85% of peak treadmill running speed (PTRS); however, the change at 70% of PTRS was not significant. The studies reported a change of a weighted average of 21%.

RPE after a maximal test was only shown to be higher in 1 of the 3 papers[20] that studied this. The reason for not finding changes in RPE levels after a maximal performance can very likely be explained by the nature of a maximal test, which if conducted correctly, should always result in a maximal or near maximal RPE score. In further support, 2 studies reported no change in RPE values in the control group.[20,28]

Daily Analysis of Life Demands for Athletes. Two papers assessed changes in the DALDA questionnaire in athletes who were functionally overreached.[26,27] Both studies showed an increase in "a" scores ("worse than normal") in part B of the DALDA questionnaire. This reflects an increase in the number of symptoms of stress (part B), whereas the number of sources of stress (part A) remained the same. The average weighted increase in "a" scores with functional overreaching was 60%.

Profile of Mood States. Changes in POMS or a subscale of the POMS scores were studied in 5 papers. Within these, 2 papers focused on changes in fatigue mood state,[19,23] whereas 2 papers focused on changes in energy index,[22,24] and 1 paper looked at changes in total score of the POMS-2 questionnaire.[21] In all papers, poorer POMS scores were observed with functional overreaching, which means that fatigue mood states were higher, the energy index was lower, and the total POMS-2 score was lower. In further support, 2 studies reported no changes in fatigue mood state scores in their control groups,[19,23] and Coates et al[21] reported unchanged POMS-2 scores in their control group. However, 2 studies reported higher fatigue mood state scores in athletes with acute fatigue,[19,23] and 1 study reported a lower energy index in athletes with acute fatigue.[24]

Interesting to note is that some of the observed responses within "power" and "heart rate" are counterintuitive, such as higher PO at the same HR and lower HR at the same intensity and faster HRRs. These counterintuitive responses can likely be explained by increased parasympathetic activity[31] together with decreased sympathetic activity[32,33] as well as increased concentrations of circulating free catecholamines[33] and an increased plasma volume, which will reduce beta–adrenergic receptor sensitivity[27] and might result in a lower PO at the same submaximal HR or an increased PO at the same submaximal HR.

Important to note is that when these responses are interpreted without the knowledge of increased RPE and fatigue levels, they could also be interpreted as indicators of a "positive" training response and stimulate a coach or athlete to keep on training too hard. Therefore, a multifactorial approach is crucial for the correct interpretation of monitoring data.

The limitations of this study were that strict selection criteria had to be used, which has limited the number of papers that could be included in this review. In addition, the systematic review has focused specifically on trained to professional endurance athletes; and therefore, the findings might differ for less trained or nonendurance athletes. Interesting to note was that all papers focused on adult athletes, whereas no papers studied youth athletes. As young talented athletes have less experience with training load and recovery and might experience high peer pressure to perform optimally,[34] they might be at a relatively high risk of overreaching. Therefore, future research should also focus on identifying markers of functional overreaching in younger athletes.

Conclusion

In conclusion, the findings of this systematic review indicate that a state of functional overreaching in trained to professional endurance athletes is reflected by changes in PO, submaximal HR, maximal HR, and HRR as well as RPE, DALDA, and POMS scores.

Functional overreaching when performing a maximal performance test[18–23] was reflected by a lower PPO and lower maximum HR as well as a faster HRR. Interestingly, no papers studied the effect of functional overreaching on maximal running speed. Both VO_2max and RPE levels did not change with the status of being functionally overreached.

Changes during a TT when functionally overreached[18,24,25] were reflected by a poorer performance (lower mean PO) and a lower submaximal HR.

Several studies used a standardized submaximal test, which was either clamped on HR (LSCT) or intensity (LSRT). These studies showed an increased PO at a fixed HR[10,18,26] or a lower HR at a fixed intensity,[27] a faster HRR,[18,21,23,26–28] and increased RPE levels.[10,18,20,22,26–28]

The DALDA and POMS questionnaire were both shown to be able to reflect a state of functional overreaching. However, the subscales of "fatigue mood status" and "energy index" were not able to differentiate between acute fatigue and functional overreaching, which makes POMS not valuable as a monitoring tool for functional overreaching.

Although both maximal performance tests and TTs have been shown to be able to reflect a state of functional overreaching, they might be less practical to perform on a regular basis than a short submaximal test that also can be used a standardized warm-up method.

Practical Applications

The findings of this systematic review provide a unique overview of which parameters change with a state of functional overreaching and how much consensus there is about these markers. This information is highly valuable for coaches and trainers when monitoring and fine-tuning the training prescription of their endurance athletes. A state of functional overreaching can not only be reflected by a maximal performance test or a TT but also by using a standardized submaximal test protocol, which might be beneficial for monitoring athletes on a regular basis.

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