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Indicators for high physical strain and overload in elite football players

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Laboratory, psychological and performance parameters as possible indicators of physical strain and overload during highly demanding competition phases were evaluated in elite male football players. In two studies with the same objective, periods of high (HE: >270 min during 3 weeks before testing) and low (LE: <270 min) match exposure were compared over the course of an entire season. In study 1 (n = 88 players of the first and second German leagues; age: 25.6 ± 4.3 years; body mass index (BMI): 23.2 ± 1.0 kg/m^2), blood count, CK, urea, uric acid, CRP and ferritin were determined. In study 2, 19 players of the third German league and the highest under-19 league (age: 19.7 ± 2.8 years; BMI: 22.8 ± 1.7 kg/m^2) were screened for individual vertical jump height, maximal velocity and by the Recovery-Stress-Questionnaire for Athletes (REST-Q Sport). The mean differences in exposure times were 180 min (study 1: quartiles: 105, 270 min) and 247 min (study 2: 180, 347 min), respectively. Significant differences were found neither in blood parameters (study 1; $P>0.36$) nor in physiological testing results or in REST-Q scores (study 2; $P>0.20$). A 3-week period of high match exposure in elite football players does not affect laboratory, psychometric and performance parameters.

Team physicians of football squads as well as athletes and coaches sometimes fear that periods of high match and/or training exposure may have negative sequelae. At least, there is some evidence that the high competitive demands of professional football can have a negative impact on match performance as well as on injury risk (Dvorak et al., 2000; Ekstrand et al., 2004). To avoid such scenarios, valid indicators for training and competition tolerability would be very useful. However, evidence-based scientific data with respect to monitor stress and fatigue in highly demanding competition periods are almost completely lacking. For this purpose, some authors recommended multi-dimensional monitoring of blood chemistry, psychological and performance parameters to quantify stress and recovery (Urhausen & Kindermann, 2002; Filaire et al., 2003; Meeusen et al., 2006).

Professional football is characterized by a high number of matches that are often associated with frequent travelling including changes of climatic conditions and sleeping away from home. International football players perform up to 76 regular matches during a season (Ekstrand et al., 2004) including weeks with additional midweek matches. During football match play, each player covers a mean distance of about 10–12 km interspersed with short-term highly intensive running and sprinting activities (on average, 17 bursts faster than 23 km h^{-1}, Stolen et al., 2005; Di Salvo et al., 2007). Further stress factors, such as media and public interest and marketing obligations, might also contribute to total individual stress.

Measurements of serum enzyme activities can represent proper tools to evaluate some kind of biomechanical demand. For instance, creatine kinase (CK) serum activity mirrors high mechanical-muscular stress during intensive training sessions (Kindermann, 1986; Stray-Gundersen et al., 1986). Particularly, eccentric muscle activity leads to increases in CK (Newham et al., 1986). Elevated levels of serum urea may result from enhanced protein catabolism and stimulated gluconeogenesis due to elevated energy requirements from several training sessions and competitions (Haralambie & Berg, 1976; Lemon & Mullin, 1980; Urhausen & Kindermann, 2002). Additionally, uric acid was thought to reflect increased metabolic strain when muscle glycogen stores are depleted (Kirwan et al., 1990). Immune system alterations might also be important factors contributing to decreased performance in highly demanding competition phases (Filaire et al., 2003;

Malm et al., 2004). Leukocyte count, CRP and – as an acute phase protein as well as an indicator of the iron status – ferritin may reflect immune system function.

From a performance perspective, during highly intensive competition periods, mechanical damage at myocyte membranes may occur, leading to a decline in lower leg explosive power (Haralambie, 1973; Noakes, 1987; Kraemer et al., 2004; Coutts et al., 2007a, b). Deteriorations in speed and power variables after highly intensive training and competition periods of 6–10 weeks duration were recently reported in team sport athletes (Kraemer et al., 2004; Coutts et al., 2007a, b). Furthermore, maximal ergometric performance is sometimes reduced in overreached athletes (Halson & Jeukendrup, 2004). This might be a result of disturbances in maximal anaerobic energy production and cardio-respiratory activity (Urhausen & Kindermann, 2002). In addition, changes in mood states were observed to be indicative of early overreaching (Fry et al., 1992). For this purpose, the Recovery-Stress-Questionnaire for Athletes (REST-Q-Sport) has been used previously to monitor the influence of intensive training on psychometric parameters in different sports (Coutts et al., 2007c; Kellmann, 2010).

Thus, it was aimed to evaluate the physical strain and, possibly, overload during highly demanding competition phases in professional football by means of a battery consisting of blood chemistry, psychological and performance testing. Because of time constraints of some professional teams and the difficulty in following up a sufficient number of elite players, two separate studies had to be conducted for this purpose.

Methods

Study 1 analyzed changes in laboratory variables relative to differences in match exposure in players from the two highest German male football leagues (SOCCERLAB). Study 2 evaluated psychological parameters and the results from physiological testing in high-level players competing under professional circumstances.

Both studies comply with the Declaration of Helsinki and were separately approved by the local ethics committees (study 1: Ärztekammer of Saarland, Saarbrücken, Germany; study 2: ethics committee of the medical faculty of the University of Münster, Germany). All players were fully informed about the risks associated with study participation and gave their written informed consent before the start of the study.

General design

All football players were tested two to four times during the German football season 2008/2009 (in study 1, there were four blood sampling times during that football season: before the pre-season preparation period, in October/November, in February/March and in April/May; the sampling time before the preparation period was not included in this analysis). For the present analysis, test results after a period with high match exposure (HE: more than 270 min in regular games during the three weeks before testing) and after a period with low match exposure (LE: <270 min in regular games during a 3-week period before testing) were compared. If a player had conducted more than two tests, the test with the lowest exposure time during the 3 weeks before testing was chosen as LE and the test with the highest match exposure was taken as HE. A priori, the minimum difference between HE and LE was set at 90 min for each individual.

Study 1

Subjects and study design

Eighteen German professional football clubs took part in the SOCCERLAB (Meyer & Meister 2010, in press) study (18 of 36 German male teams of the first and second Bundesliga in season 2008/2009). Five hundred and thirty-two players originally agreed to participate (52% of the registered players during the season 2008/2009). A questionnaire had to be completed by each player before each blood sample to detect factors that might interfere with some laboratory parameters. In cases of failure to pass the pre-season medical screening examination, overt diseases and injuries, or not sticking to training requirements before blood sampling, players were excluded from participation ($N = 65$). From the remaining 467 participants, 231 football players were tested at least twice during the season. Players who did not fulfill the requirements for contrasting high and low match exposure as described in the preceding paragraph were excluded ($N = 143$). Thus, 88 players (age 25.6 ± 4.3 years; height 1.84 ± 0.07 m; weight 78.4 ± 7.0 kg; BMI 23.2 ± 1.0 kg/m^2) remained for the comparison HE vs LE. There were no significant differences in any obtained variable between dropouts and players who were analyzed ($P > 0.28$).

Blood samples were drawn in the morning after an overnight fast from an antecubital vein in a supine position. Samples consisted of 2.7 mL EDTA-blood and 9 mL whole blood. Whole blood was centrifuged within 20 min after sampling. To standardize exercise exposition before all blood sampling, players had to perform exactly one team training on the day before testing and no exercise in the morning before sampling. Data on anthropometric characteristics were taken from the website http://www.kicker.de and match exposure from http://www.fußballdaten.de (regularly reporting all exposure data of athletes playing in the German professional football leagues).

Laboratory methods

For hematological parameters, a blood count was performed including red blood cells (RBC), white blood cells (WBC), hemoglobin (HGB) and hematocrit (HCT) – (Sysmex K-100, Sysmex, Norderstedt, Germany).

From serum analysis, the following parameters were determined [determination method; intra- and inter-assay coefficient of variation (CV) in parentheses]:

creatine kinase (CK) – (enzyme activity measurement, CK, HK, G6PDH, optical test; 3.5%; 5.3%), urea (urease-GLDH-UV-test; 3%; 4.5%), uric acid (uric) – (uricase method according to Trinder; 2%; 3%), C-reactive protein (CRP) – (immune turbidimetry; CRP; 5%; 7.5%; all by Synchron CX-5 Delta, Beckman Coulter, Krefeld, Germany) and ferritin (enzyme immunoassay; 3.6%; 4.3%; by Access Immunoassay System, Beckman Coulter).

Some parameters were excluded from analysis when one of the following confounders was present:

infection – leukocytes, CRP, ferritin
intramuscular injection – CK
intake of allopurinol or other drugs affecting uric acid serum levels – uric acid
iron supplementation – ferritin

Study 2

Subjects and study design

Two football teams (a total of 32 field players) competing and training under professional circumstances (third German league as well as the highest U-19 league including four U-20 and U-19 national team members) agreed to participate in this study. A total of $N = 19$ players (age: 19.7 ± 2.8 years, height: 1.82 ± 0.06 m, weight: 75.3 ± 8.3 kg, BMI: 22.8 ± 1.7 kg/m^2) fulfilled the above-mentioned criteria for HE and LE and were thus included in statistical analyses. There were no significant differences in any obtained variable between dropouts and players who were analyzed ($P > 0.15$). Testing consisted of a psychometric questionnaire, vertical jump testing and a ramp-like maximal running field test. There was at least 1 day between the tests and the last match and no intensive training session on the day before testing. Exposure times in training and matches (regular and friendly matches) were recorded by the coaches for each player individually.

Recovery-Stress-Questionnaire for Athletes (REST-Q Sport (Kellmann & Kallus, 1999))

This questionnaire consists of 52 items (REST-Q-52), which can be assigned to 19 sub-scales and enables a detailed, multi-dimensional analysis of the individual recovery-stress state. The items have to be self-rated on a 7-point Likert scale ranging from 0 (never) to 6 (always), indicating how often the subject has participated in various activities during the last 72 h. The 52 items can be assigned to 10 stress-associated subscales (summed up to a Total Stress score) and 9 recovery-associated subscales (Total Recovery score). The questionnaire shows satisfying reliability as well as convergent validity (Kellmann & Kallus, 1999). Players were asked to complete the Rest-Q Sport at the beginning of all testing sessions before warm-up and all other tests. For a detailed review of the REST-Q Sport, the reader is referred to Kellmann (2010).

Vertical jump tests

Lower limb explosive power was assessed using a vertical counter movement jump (CMJ) as well as a drop jump (DJ) from a drop height of 0.35 m. Flight times (t in [s]) and contact time were measured using a contact mat (0.72×0.56 m). Jumping height was calculated according to the formula: height $= 1/8 \times 9.81\,\mathrm{m\,s^{-2}}\,t^2$. Both jumps were performed with the hands fixated at the hips. During CMJ, players had to dip from a standing position and jump as high as possible. The DJ had to be performed aiming at maximum height with minimum contact time (Young et al., 1995). Both jumps were performed several times (5–7) and the best four performances were recorded and averaged for statistical analyses.

Maximal running capacity

Maximal running speed (V_{max}) was assessed using an incremental ramp-like exercise test until volitional exhaustion [modified Montreal Track Test (Rampinini et al., 2007)]. The test was completed on a 200-m track marked by cones placed every 50 m on an artificial turf surface. Following an acoustic signal, the subjects performed the incremental field test, starting from 8.0 km h^{-1}, with the speed increasing by 1.0 km h^{-1} every minute. The test was terminated when a player twice failed to reach the next cone in the required time or if he felt unable to cover another interval at the given speed. During the test, athletes were verbally encouraged by the technical staff as well as by their team coach. If the last step was not completed, the peak speed was calculated using the formula

$$V_{max} = V_{compl} + (t/60\,\mathrm{s})[\mathrm{km\,h^{-1}}]$$

with V_{compl} [km h^{-1}] being the last completed step and t [s] the time of the uncompleted step.

Heart rate was continuously recorded by means of a heart rate monitor (Polar S610 and S810, Polar Electro, Kempele, Finland). The highest heart rate

before termination was taken as the maximum heart rate. Capillary blood samples (20 μL) were taken before, directly after termination as well as 2, 4 and 6 min after cessation from the hyperemized earlobe for the determination of maximal blood lactate concentrations ($[bLa]_{max}$, enzymatic-amperometric method, EBIO Plus, Eppendorf, Hamburg, Germany; CV = 2.9% for lactate values of 7 mmol L^{-1}).

Statistics

Testing for a normal distribution was conducted using the Kolmogorov–Smirnov test for all dependent variables. Exposure times and laboratory markers were not normally distributed and thus presented as medians with upper and lower quartiles. For a comparison of laboratory parameters between HE and LE, a Wilcoxon test was used. Differences between HE and LE conditions were given as mean with 95% confidence intervals (95% CI). For comparisons of performance and psychometric results at LE and HE, a Student's t test was performed. Pearson's product–moment analysis was conducted to assess the correlations between differences in REST-Q Total Stress and Recovery scores and the corresponding differences in performance parameters between HE and LE. Spearman's rank correlation coefficient was calculated to analyze the correlation between absolute differences in the match exposure time between HE and LE and absolute differences in the laboratory, performance and psychometric parameters, respectively. A P value for the α-error of <0.05 was accepted as statistically significant.

Results

Match exposure

The median of differences in exposure times between HE and LE during the 3 weeks before testing was 180 min in study 1 (lower quartile: 105 min, upper quartile: 270 min) and 247 min in study 2 (lower quartile: 180 min, upper quartile: 347 min), respectively.

Absolute match exposure was two to three times higher during HE compared with LE ($P<0.001$; Study 1: 0.6 (LE) vs 1.2 matches/week (HE); Study 2: 0.4 (LE) vs 1.3 matches/week (HE)).

Study 1

Laboratory results

The results of laboratory markers after a low and a high match exposure are given in Table 1. All the parameters remained unaffected ($P>0.36$).

Study 2

Performance tests

There were no significant differences between HE and LE in all the performance parameters ($P>0.20$; Table 2), although a tendency toward higher CMJ heights after HE was observed ($P=0.06$).

Recovery-Stress-Questionnaire for Athletes

Also, there were no significant differences in the Total Stress and Total Recovery score between HE and LE (Table 2). Furthermore, the Recovery-Stress-Questionnaire for Athletes did not indicate significant differences between LE and HE for most of the REST-Q sub-scores ($P>0.37$). Only the stress subscore Physical Complaints tended to be higher after HE compared with LE ($P=0.09$; Fig. 1).

No significant correlations between differences in Total Stress or Total Recovery Score and differences in any performance parameter were observed for HE and LE (data not presented; $P>0.12$). There was only a significant correlation between differences in match exposure before HE and LE and differences in laboratory parameters for hemoglobin (data not

Table 1. Laboratory parameters during 3 weeks of low and high match exposure (data presented as median with upper and lower quartiles, and, differences of HE – LE as mean, 95 % confidence interval and minimum and maximum)

	N	Low exposure (LE)		High exposure (HE)		*P* value	ΔHE – LE			
		Median	Quartiles	Median	Quartiles		Mean	95% CI	Min	Max
WBC (× 10^3 μL^{-1})	49	5.7	4.7/6.4	5.4	4.7/6.4	0.43	– 0.2	– 0.5/0.2	– 4.4	3.0
RBC (× 10^6 μL^{-1})	84	4.91	4.7/5.2	4.99	4.7/5.2	0.78	– 0.01	– 0.06/0.04	– 0.50	0.51
HGB (g dL^{-1})	84	14.9	14.4/15.7	15.0	14.5/15.6	0.77	0	– 0.2/0.1	– 1.8	1.7
HCT (%)	84	42.6	40.8/44.5	42.4	41.3/44.2	0.59	– 0.1	– 0.6/0.3	– 4.5	4.3
CK (U L^{-1})	68	308	201/495	305	199/499	0.89	28	– 46/103	– 970	1014
Urea (mg dL^{-1})	88	36	31/41	36	31/41	0.36	– 1	– 2/1	– 26	19
URIC (mg dL^{-1})	87	5.6	5.0/6.1	5.6	4.9/6.0	0.91	0	– 0.2/0.1	– 2.7	1.8
CRP (mg L^{-1})*	49	1.0	1.0/1.0	1.0	1.0/1.1	0.74	– 0.3	– 1.2/0.6	– 17.9	5.8
Ferritin (μg L^{-1})	48	76	44/99	72	44/96	0.87	– 2	– 8/4	– 73	39

*If CRP was not traceable, it was set at 1.0 mg/L.

WBC, white blood cells; RBC, red blood cells; HGB, hemoglobin; HCT, hematocrit; CK, creatine kinase; URIC, uric acid; CRP, c-reactive protein.

Table 2. Results of performance testing and Total Stress and Total Recovery Score at LE and HE (data as mean and standard deviation (SD) and differences of HE – LE as mean, 95 % confidence interval and minimum and maximum)

$N = 19$	Low exposure (LE)	High exposure (HE)	P value	ΔHE – LE			
	Mean (SD)	Mean (SD)		Mean	95% CI	Min	Max
CMJ height (cm)	37.1 (3.5)	38.2 (3.3)	0.06	1.0	0/2.1	– 3.1	5.5
DJ height (cm)	35.0 (4.7)	35.8 (4.3)	0.20	0.9	– 0.5/2.2	– 6.1	4.6
DJ contact time (ms)	193 (25)	190 (33)	0.43	– 3	– 12/5	– 29	36
V_{max} (km h^{-1})	18.3 (0.9)	18.4 (0.8)	0.61	0.1	– 0.3/0.5	– 0.9	1.6
HR_{max} (min^{-1})	191 (10)	191 (9)	0.72	0	– 2/3	– 7	14
$lactate_{max}$ (mmol L^{-1})	10.3 (2.7)	10.3 (2.2)	0.91	– 0.1	– 1.0/0.9	– 3.4	3.9
Total stress score	20.8 (6.1)	21.4 (7.1)	0.73	0.6	– 3.2/4.5	– 12.8	17.5
Total recovery score	31.5 (5.7)	31.4 (7.6)	0.94	– 0.1	– 4.1/3.8	– 17.3	20.0

CMJ, counter movement jump; DJ, drop jump; V_{max}, maximal running speed; HR_{max}, maximal heart rate; $lactate_{max}$, maximal blood lactate concentration.

presented; $r = -0.25$; $P = 0.02$; all other laboratory parameters: $r = -0.20$ to 0.22; $P > 0.12$). No significant correlations were found between differences in the match exposure time before HE and LE and differences in performance as well as psychometric parameters, respectively (data not presented; $r = -0.23$ to 0.26; $P > 0.29$).

Discussion

We assessed the effects of a 3-week period of high match exposure compared with a low match exposure period in German male elite football players on laboratory markers, physiological testing and psychometric parameters. No relevant alterations in anyone of the analyzed parameters were observed. These results gain importance because they were obtained in top-level football players, which enables generalization to other elite teams.

Biochemical monitoring has previously been investigated as an indicator of high physical strain and overload (Kindermann, 1986; Stray-Gundersen et al., 1986; Kirwan et al., 1990; Urhausen & Kindermann, 2002). However, in football, there are only studies with small sample sizes (Filaire et al., 2003) or investigations analyzing the chronic changes (Biancotti et al., 1992; Rebelo et al., 1998; Malm et al., 2004) available. In team sports, significant changes of laboratory values after high-intensity training periods were only reported for CK in rugby league players (Coutts et al., 2007b) and uric acid in elite French football players (Filaire et al., 2003), whereas other parameters remained unaffected. In the present investigation, no relevant alterations of laboratory markers after 3 weeks with high competitive demands were observed. Thus, although acute exercise-induced changes of blood parameters are well documented (Noakes, 1987; Gillen et al., 1991; Biancotti et al., 1992; Meyer et al., 2001; Brun, 2002), no chronic effects seem to result from 3 weeks of high competitive loads.

Intensive training leading to elevated CK levels might acutely lead to high enzyme activity as a result of massive skeletal muscle fiber damage in football (Mougios, 2007). It is well known that CK leaks into the plasma after a high training or competition exposure with repeated intense contractions (Clarkson et al., 1992; Noakes, 1987; Mougios, 2007). Therefore, the football-specific movement pattern with frequent stop-and-go-actions and direction changes might contribute to an increasing CK activity. CK levels are elevated above the reference values for the normal population in HE and in LE. However, CK can be elevated for the next day after intensive training, because it has a biological halftime of about 18 h (Thomas, 2008). For this reason, CK levels are neither appropriate to indicate long-term strain as in HE nor to evaluate a state of muscle recovery because restoring processes usually last much longer. In addition to creatine kinase, changes in the serum parameters urea and uric acid are also regarded as markers of high physical strain in elite athletes (Haralambie & Berg, 1976; Kirwan et al., 1990). In our study, neither urea nor uric acid showed relevant alterations between high and low exposition loads. This observation can be attributed to no elevated physiological requirements and, consequently, no relevantly enhanced protein catabolism and no relevantly stimulated gluconeogenesis during highly demanding competition phases.

Performance and psychometric testing have previously been stated to be potentially suitable means to diagnose high physical strain in team sport athletes (Coutts et al., 2007a, b, c; Faude et al., 2011). For instance, Coutts et al. (2007a) reported reductions in maximal oxygen uptake, maximal aerobic velocity and performance in a multi-stage fitness test after 6 weeks of overload training in semi-professional rugby players. In addition, Kraemer et al. (2004) reported deteriorations in speed, jumping heights and strength parameters during an 11-week competitive period (including 19 matches) in 11 collegiate football players. Those impairments were

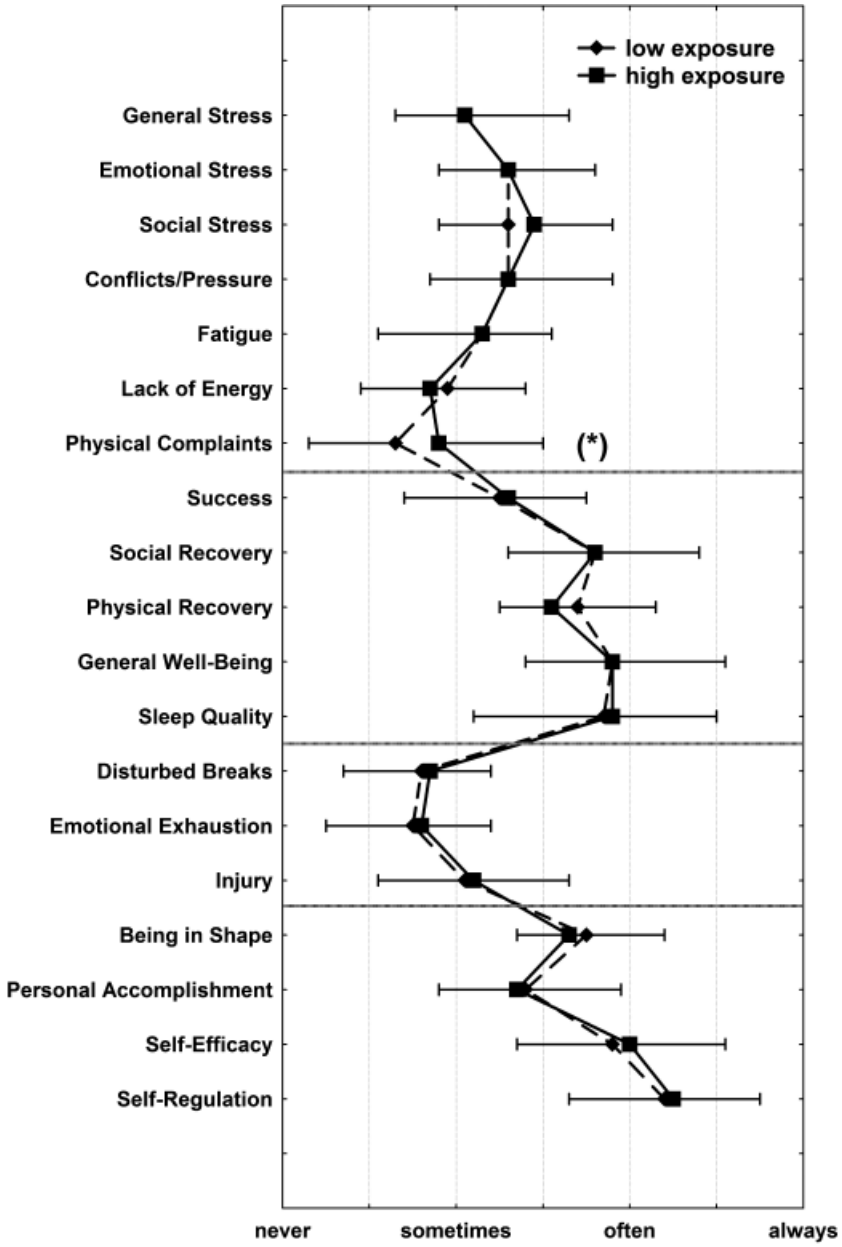

Fig. 1. Results of the Recovery-Stress-Questionnaire at low and high exposure (data as mean and standard deviation (SD); $^{*}P = 0.09$).

considered critical for football players (Kraemer et al., 2004). Similar changes in power parameters after an intensive training period in rugby players were reported by Coutts et al. (2007a, b). No such changes were observed in the present study, and, thus, it seems justified to conclude that no relevant physiological signs of fatigue or overreaching were present at HE compared with LE. In contrast, jumping heights were even slightly increased at HE.

Although psychometric testing is widely accepted as a sensitive and practicable marker for the early recognition of high physical strain and overload (Urhausen & Kindermann, 2002; Coutts et al., 2007c; Kellmann, 2010), neither Total Stress nor the Total Recovery score and any sub-scores indicated significant alterations in recovery stress state. There was only a tendency toward slightly higher values in the sub-score Physical Complaints at HE. In addition to laboratory and performance parameters, these findings also suggest that excessive stress and a lack of recovery were not present after a 3-week period of high match exposure.

Limitations of study

It might be argued that the average exposure during HE in the present study was too low to induce relevant signs of excessive stress. However, the average match

exposure in our study was similar to that of other professional male football players participating in the UEFA Champions League study (Ekstrand et al., 2010). This indicates that the match exposure times of elite football players are within the range of the studied population. Sub-groups with players who played at least four matches in 3 weeks (study 1: $N = 31$; study 2: $N = 9$) showed similar results (data not presented). Therefore, the present results seem to have high external validity. Otherwise, training exposure (only in study 1) and external stressors (frequent travelling, great interests of media and economics) in highly demanding and critical seasonal phases were not recorded. It seems possible, for instance, that the training amount in study 1 was intentionally reduced during phases of high competitive demands to avoid excessive overload. However, this was not the case in study 2 (6.5 training hours per player and week during HE and LE each).

A further limitation might be seen in the low number of parameters that were assessed in the present study. A huge amount of possible markers has been investigated during the past decades, including biochemical, immunological, vegetative, hormonal, physiological and psychological parameters (Urhausen & Kindermann, 2002). The present study was not designed as a broad-based analysis of a wide variety of parameters. It was rather intended to assess stress and fatigue with a well-founded economical test panel that can be easily applied in daily practice to support team physicians and coaches in applied settings.

Match play analysis might be regarded as the probably best indicator of the real competition performance of professional football players and might provide the most reliable information on possible performance decrements due to the high competitive load during HE. Therefore, such an approach might be attractive for future studies on this topic, although it is complicated and expensive. Match performance of football players, however, is dependent on tactical aspects and on the opponent's behavior (Di Salvo et al., 2007), probably leading to high match-to-match variability of high-intensity activities (Gregson et al., 2010). Thus, the value of such an approach to detect acute fatigue-induced performance decrements might be limited.

Perspectives

Physical strain and overload during highly demanding competition phases in elite football players was evaluated by means of laboratory, psychological and performance testing. Data on physiological demands during phases of a high match exposure in this population are scarce. All parameters were determined in periods of a 3-week high vs low match exposure before testing in high-level German male football leagues. From the results of the present study, it can be concluded that a 3-week period of high competitive demands does neither lead to relevant changes in blood parameters (blood cell count and biochemistry) nor to performance decrements and psychological deteriorations in high-level German football players. The physiological strain of a 3-week high match exposure does not seem to be as high as it is sometimes assumed by trainers and physicians. Further investigations during a more extended period of time with high competitive demands (more than 3 weeks with midweek matches) might be considered in further research. However, such an approach would only have relevance for very few outstanding players.

Key words: soccer, match schedule, fatigue, recovery, blood monitoring, performance testing.

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