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ORIGINAL ARTICLE

Is an elevated submaximal heart rate associated with psychomotor slowness in young elite soccer players?

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Abstract
The aim of the present study was to find early markers for overreaching that are applicable in sport practice. In a group of elite soccer players aged 15–18, the stress–recovery balance and reaction times before and after exercise were assessed. Overreaching was indicated by an elevated submaximal heart rate during a sport-specific field test. Submaximal changes in heart rate were prospectively monitored by means of monthly Interval Shuttle Run Tests during two competitive seasons. Out of 94 players, seven players with an elevated heart rate of at least one month could be included in the study, together with seven controls, matched for age, body composition, training and performance level. The stress–recovery balance was assessed with the Dutch version of the Recovery Stress Questionnaire (RESTQ-Sport). The soccer players with an elevated heart rate reported a disturbed stress–recovery balance (Mann–Whitney test, $P < 0.05$). An ANOVA for repeated measures of reaction times revealed a significant main effect of time ($F_{1,12} = 13.87$, $P < 0.01$) indicating an improvement of psychomotor speed. No differences between groups were found. We conclude that soccer players with an elevated submaximal heart rate of at least one month share a disturbed stress–recovery balance, but they could not be distinguished from controls based on reaction time after strenuous exercise.

Keywords: *Stress recovery balance, overtraining, reaction time, team sports*

Introduction

Researchers, athletes, coaches and sports physicians have been searching for early markers of overreaching (OR). It is assumed that an early detection of OR might prevent athletes from overtraining syndrome (OTS) (Meeusen et al., 2006). Characteristic symptoms of OR such as fatigue, disturbances in perception, coordination and concentration problems have led to the introduction of reaction time as a possible marker to recognize OR at an early stage (Lehmann, Foster, & Keul, 1993; Nederhof, Lemmink, Visscher, Meeusen, & Mulder, 2006; Rietjens et al., 2005). This idea was supported by findings of psychomotor slowness in patients with chronic fatigue syndrome and major depression, showing symptoms and hormonal dysfunction similar to OR (Armstrong & VanHeest, 2002; Fry, Morton, & Keast, 1991a, 1991b; Nederhof et al., 2006; Nederhof, Zwerver, Brink, Meeusen, & Lemmink, 2008). Measuring reaction time certainly has some advantages over other early markers, such as questionnaires or blood parameters. A reaction time test is objective, applicable in training practice, not too demanding for athletes, and can be performed on a regular personal computer (Nederhof et al., 2006).

Based on the duration of performance stagnation or decrement, combined with the severity of

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symptoms, terminology has been proposed that divides OR into functional overreaching (FOR) and nonfunctional overreaching (NFOR) (Meeusen et al., 2006; Nederhof et al., 2006). FOR refers to performance decrement with a planned recovery period varying from days to weeks. If, however, performance decrement lasts longer (weeks to months) and coincides with more severe symptoms, this is referred to as NFOR. The overtraining syndrome (OTS) is the final stage of the continuum with documented recovery periods from months to years. Since the exact duration and severity of performance decrement and symptoms are not defined, a clear distinction between these three phases is still difficult to make.

So far, only four studies investigated reaction times in OR (Nederhof, Lemmink, Zwerver, & Mulder, 2007; Nederhof, Visscher, & Lemmink, 2008; Nederhof, Zwerver, et al., 2008; Rietjens et al., 2005). In two studies FOR was induced in well-trained cyclists by increasing training load during a training camp (Nederhof et al., 2007; Rietjens et al., 2005). In both studies, subjects who were OR were shown to have a slower reaction time than subjects in the control group. In line with these findings, Nederhof, Zwerver, et al. (2008) reported slower reaction times in a speed skater with NFOR. Furthermore, this same researcher reported a relationship between psychomotor speed and perceived performance in a group of varsity rowers over course of a season (Nederhof, Visscher, et al., 2008).

In the present study we hypothesize that assessing reaction time immediately after maximal exercise enlarges differences between healthy and OR athletes. It is known that acute exercise facilitates choice reaction times in healthy athletes (Davranche & Audiffren, 2004; Davranche, Audiffren, & Denjean 2006; Davranche, Burle, Audiffren, & Hasbroucq, 2005, Audiffren, & Hasbroucq, 2006; Lemmink & Visscher, 2005) and is associated with activity of the sympathoadrenal system (SAS) and the hypothalamic–pituitary–adrenal axis (HPAA) (McMorris et al., 2009). Both the SAS and HPAA appear to play a role in exercise–cognition interaction (McMorris et al., 2009). Recent studies have shown that neuroendocrine differences between healthy and OR athletes become apparent directly after acute exercise (Meeusen et al., 2004, 2010; Nederhof, Zwerver, et al., 2008). Based on this, differences in psychomotor speed between OR subjects and controls are expected to show the largest differences immediately after exercise.

Since it is unethical to induce OTS, most studies have been done retrospectively. In order to prevent athletes developing OTS, more research is needed that focuses on the early symptoms of FOR and NFOR. Inducing fatigue with a short intensified training period or training camp seems a valid alternative. However, these studies are usually designed to increase physical performance and also do not incorporate the normal seasonal variability in training-related and psychosocial stress and recovery. Furthermore, inducing fatigue does not necessarily lead to performance stagnation or decrement, which is considered to be the hallmark of OR (Meeusen et al., 2006). Therefore, longitudinal research is needed that monitors performance changes with a non-fatiguing test, in order to detect the first symptoms of FOR and NFOR.

In the current study design we monitored changes in submaximal heart rate during a monthly standardized exercise test, as a marker of physical fitness. As an increase in submaximal heart rate larger than the normal day-to-day variation can be interpreted as a mal-adaptation to training (Lamberts et al., 2009), players who were possibly OR could be identified. The aim of this study was to prospectively monitor changes in submaximal heart rate as indicator of OR and assess the stress–recovery balance and reaction time to exercise. We hypothesized that soccer players classified with an elevated submaximal heart rate can be distinguished from a control group by a disturbed stress–recovery balance and slower reaction time to a maximal bout of exercise.

Methods

Subjects

During the 2006–2007 and 2007–2008 competitive seasons a total of 94 players between 15 and 18 years old were monitored, for at least one season. All subjects had played for several years at the highest level in the Netherlands and followed a balanced training program which was set by a professional coaching panel. The players were part of the under 17 (U17) and under 19 (U19) squad who participated in the Dutch premier league and are regarded as the top 1% soccer players in their age groups. The training program consisted of aerobic, speed, agility, technical and tactical training. The players also completed an individualized resistance training program once per week. Soccer players with an elevated submaximal heart rate measured at two monthly consecutive field tests were invited to the sports medicine laboratory for medical follow-up (Figure 1). The study was ethically approved by the Central Committee on Research involving Human Subjects. All participants (and both parents of under-aged participants) gave informed consent.

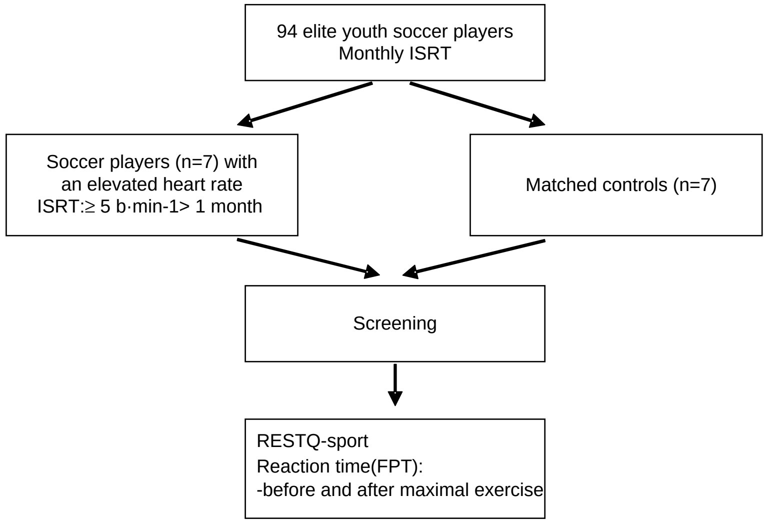

Figure 1. Flowchart study design. ISRT: Interval Shuttle Run Test; RESTQ-sport: Recovery Stress Questionnaire; FPT: Finger Pre-cueing Task.

Interval Shuttle Run Test

To determine performance changes in soccer players, a submaximal Interval Shuttle Run Test (ISRT) with sufficient reliability and validity was used (Lemmink & Visscher, 2003; Lemmink, Visscher, Lambert, & Lamberts, 2004). The tests were performed every month on an artificial pitch at the start of the training as a substitute for the warm-up. All tests were performed after a day of rest. Submaximal intensity was set at 70% of the maximal amount of runs at the start of the season. During the ISRT, players alternately ran for 30 seconds and walked for 15 seconds. Running speed increased from 10 $km \cdot h^{-1}$ every 90 seconds up to 15 $km \cdot h^{-1}$ depending on baseline maximal running performance. A fixed number of runs was used for every individual during an entire season. Heart rate was recorded at 5-s intervals (Polar, Kempele, Finland) and we calculated the average over the last 60 seconds of running. Since variations in heart rate on an individual level during submaximal interval-based running at 85–90% of the heart rate maximum is reported to be 3 ± 1 bpm (Lamberts & Lambert, 2009), players with a heart rate increase of $\geq$ 5 bpm were included. This increased heart rate at two consecutive occasions, with absence of clear other reasons (see medical screening), was interpreted as a mal-adaptation to training and a state of FOR or NFOR (Armstrong & VanHeest 2002; Lamberts, Rietjens, Tijdink, Noakes, Lambert, 2010; Schmikli, Brink, de Vries, & Backx, 2011; Wilmore et al., 1996).

Medical screening

All injuries and/or illnesses were closely assessed and recorded by the club's medical staff (i.e. physicians and physical therapists) according to the FIFA registration system (Fuller et al., 2006). An injury was defined as any physical complaint sustained by a player that resulted from match play or training. Injuries were recorded if a player received medical attention for more than one day or was unable to take part in training or were ineligible for selection for matches. An illness was defined as a circumstance in which the player felt that they were limited or unable to perform normal training or match (e.g. flu, cold, virus, etc.).

Soccer players who presented with abnormal heart rate response to the submaximal ISRT were included in the study, together with controls who did not suffer from illness and injury and also had a normal heart rate response (Brink, Visscher, Arends, et al., 2010). All players were invited to the laboratory, within one week after the field performance test, for medical follow-up. A sports physician followed previous recommendations for athlete screening to exclude cardiovascular contraindications, as well as to exclude other well-known causes of fatigue and performance decrement (e.g. viral infections, anaemia, allergy, diabetes, hypothyreoidea) (Meeusen et al., 2006; Uusitalo, 2001). None of the referred players showed any other clear reasons for an elevated submaximal heart rate than a state of FOR or NFOR.

Recovery Stress Questionnaire (RESTQ-Sport)

The Dutch version of the RESTQ-Sport was administered to assess the psychosocial stress–recovery state of players. The RESTQ-Sport consists of general and sport-specific stress and recovery categories. The players were instructed to rate the 77 items on a Likert-type scale, with anchors of 0: never and 6:

always, indicating how often they had participated in recovery and stress-related activities during the last 4 weeks (Kellmann & Kallus, 2001). High scores on the stress-associated scales reflect subjective stress, whereas high scores on the recovery-oriented scales represent recovery activities. The stress–recovery state was calculated as the sum of the recovery scores minus the sum of the stress scores (Coutts, Reaburn, Piva, & Rowsell, 2007; Jurimae, Maestu, Purge, Jurimae, & Soot, 2002; Kellmann & Kallus, 2001). Whilst this method of analysis is not included in the original RESTQ-Sport Manual (Kellmann & Gunther, 2000), previous research has provided construct evidence for its validity as a practical measure for assessing global changes in the stress–recovery balance in athletes (Coutts et al., 2007; Jurimae et al., 2002; Kellmann & Kallus, 1999). The reliability and validity of the Dutch RESTQ-Sport has been reported as good by Nederhof, Brink and Lemmink (2008).

Maximal exercise protocol

The soccer players with an elevated heart rate and controls were invited to the laboratory within one week after the field performance test. They were not allowed to eat or consume products containing caffeine 2 hours before the first exercise test. A graded incremental exercise test until exhaustion on a treadmill was performed to induce acute fatigue. The tests were performed between 13.00 and 18.00 hours. The soccer players started with a 3 minute warm-up at 8 $km \cdot h^{-1}$. Every 2 minutes, speed increased by 1 $km \cdot h^{-1}$ starting at 10 $km \cdot h^{-1}$. Heart rate was monitored at 5-s intervals using a sports tester (Polar, Kempele, Finland). A sports physician supervised all exercise tests.

Finger Pre-cueing Task

Reaction times were measured using the Finger Pre-cueing Task (FPT) (Adam et al., 1998) before and after the maximal exercise test. Subjects responded to stimuli displayed on a computer screen with button press responses by index and middle fingers of both hands (the two left most and two right most). Stimuli were plus (+) signs shown in the middle of the computer screen. The stimulus display consisted of a warning signal, a cue signal and target signal. The warning signal was a row of four plus signs. After a preparation interval of 500 ms, the target interval appeared on the computer screen in a position indicated by the cue. The target signal consisted of one plus sign indicating the final cue location. Four pre-cue conditions were distinguished. In the uncued condition the cue signal consisted of four plus signs in all four positions, preventing the possibility of selective response preparation. In the hand cued condition, the cue signal consisted of two plus signs at the two left most or two right most positions, indicating the middle finger and index finger of the left hand or the right hand respectively. In the finger cued condition the cue signal consisted of two plus signs at the two outer or the two inner positions, indicating the two middle fingers or two index fingers. In the neither cued condition the cue indicated the middle and index finger of different hands. An inter trial interval of 1000 ms separated the response from the start of the next trial. Subjects were familiarized with the FPT and performed 10 practice trials before each test session. A test session consisted of 160 trials. Mean reaction times were calculated for each cue condition. Incorrect responses, as well as reaction times shorter than 150 ms or longer than 1000 ms were omitted in the calculation of mean reaction time.

Statistical analyses

Statistical analyses were performed with SPSS 16.0 software (SPSS Inc., Chicago, IL, USA). Mann–Whitney tests were used to analyse differences in stress, recovery and the outcome measures of the maximal exercise protocol, between soccer players with an elevated heart rate and controls. Reaction times were analysed using a two-way ANOVA for repeated measures, with GROUP (players with an elevated heart rate or control) as between-subject

Table I. Descriptive statistics (mean $\pm s$) of the soccer players with an elevated heart rate and controls.

	Elevated heart rate			Controls		
	M		*s*	M		*s*
Age (years)	17	±	1	17	±	1
Height (cm)	174.6	±	6.51	178.9	±	5.44
Weight (kg)	71.4	±	6.05	68.9	±	7.17
BMI ($kg \cdot m^{-2}$)	23.5	±	2.31	21.5	±	2.22
Runs maximal ISRT	112.7	±	12.49	110.9	±	21.95
Runs submaximal ISRT	78.1	±	6.41	78.3	±	11.98

ISRT = Interval Shuttle Run Test

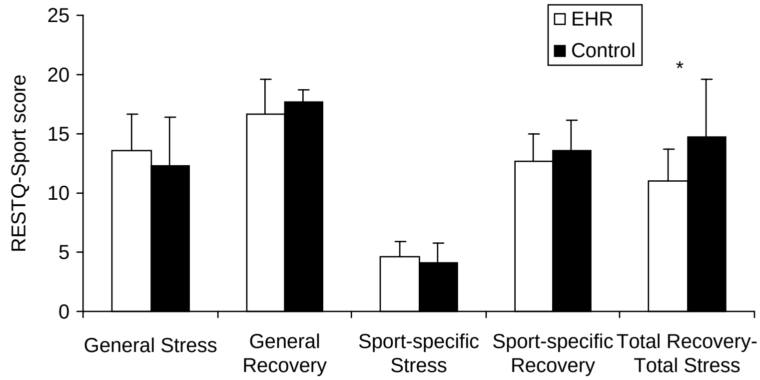

Figure 2. General and sport-specific stress and recovery mean $\pm s$ in soccer players with an elevated heart rate (EHR) and controls. $^{*}P<0.05$.

factor and TIME (pre- or post-test) and CONDITION (uncued, handcued, finger cued or neither cued) as within-subject factors. T-tests were used for post-hoc analyses with Bonferoni correction for multi comparison. Significance level was set at $P<0.05$.

Results

Field test performance and maximal exercise protocol

Seven players with an elevated submaximal heart rate were included, together with seven controls (Table I). The average heart rate at the end of the ISRT was 187 bpm and 180 bpm respectively, which corresponds to 85–90% of their maximal heart rate. The soccer players with an elevated heart rate showed, with a fixed number of runs at the ISRT, a mean increase of 9 ± 1 bpm (range 8–11) compared to baseline, which was interpreted as a decrease in submaximal physical fitness. No significant differences were found in mean time to exhaustion during the maximal exercise test in the soccer players with an elevated heart rate and the control group (17:36 ± 2:13 and 17:31 ± 2:22 min). Maximal heart rate at the end of the maximal exercise protocol showed a tendency to be slightly lower compared to the control group (188 ± 12 bpm and 199 ± 6 bpm, respectively; $P=0.12$).

Stress and recovery

The soccer players with an elevated heart rate revealed no significant differences in stress and recovery scores, for both general and sport-specific categories (Figure 2). The stress–recovery state was significantly lower for the soccer players with an elevated heart rate compared to controls indicating a disturbed balance.

Reaction times

Table II displays mean $\pm s$ and percentages of reaction times (ms) of the uncued, hand cued, finger cued and neither cued condition pre- and post-test of soccer players with an elevated heart rate and controls. A significant main effect for TIME was found ($F_{1,12}=13.87$, $P<0.01$), indicating that reaction times were faster after exercise than before exercise. In addition, a significant main effect was found for CONDITION ($F_{3,36}=18.10$, $P<0.0001$), indicating a difference in reaction time between the four different testing conditions. Post-hoc analysis revealed that reaction times in the uncued and neither cued conditions were slower than in the other two conditions (hand and finger cued). No interaction effects (TIME × CONDITION) were found between the groups, indicating that reaction times did not differ between

Table II. Mean $\pm s$ reaction times (ms) of the uncued, hand cued, finger cued and neither cued condition pre- and post-test of soccer players with an elevated heart rate (EHR) and controls.

		Uncued #				Hand cued				Finger cued				Neither cued #			
		M		*s*	%	M		*s*	%	M		SD	%	M		*s*	%
Pre-test	EHR	470	±	72	100	420	±	54	100	446	±	58	100	480	±	77	100
	Control	445	±	57	100	412	±	81	100	434	±	89	100	471	±	76	100
Post-test *	EHR	423	±	32	90	371	±	29	88	390	±	29	88	418	±	46	87
	Control	441	±	65	99	378	±	46	92	402	±	66	91	420	±	75	89

ISRT = Interval Shuttle Run Test
$^{*}P<0.01$ between pre- and post-test in both groups
$\#P<0.001$ between cue conditions in both groups.

the soccer players with an elevated heart rate and controls.

Discussion

In this study we hypothesized that soccer players with an elevated heart rate can be distinguished from a control group by a disturbed stress–recovery balance and slower reaction times before and after a maximal exercise bout. In this study an abnormal increase in submaximal heart rate (Lamberts & Lambert, 2009) as indicator of performance decrement was used to select players who were likely OR. This is in line with the position statement of the European College of Sport Sciences (Meeusen et al., 2004) and has previously been used by Brink, Visscher, Coutts and Lemmink (2010) and Schmikli et al. (2011).

The fact that performance stagnation or decrement as a hallmark of OR coincides with a disturbed stress–recovery balance is in line with previous research that consistently showed that subjective ratings of stress and recovery are sensitive for recognizing OR in team sport at an early stage (Coutts & Reaburn, 2008; Coutts et al., 2007; Lamberts et al., 2010). Although the coaches were not provided with feedback in this study, a possible limitation of psychometric questionnaires such as the RESTQ-Sport is that the responses can be manipulated by players. Especially when applied in team sports, the outcome of subjective measures may be influenced by the players' fear of being deselected from the team. Therefore, an objective measure such as reaction time that can support impending fatigue is warranted.

Although the players with an elevated heart rate indeed showed a disturbed stress–recovery balance, we did not observe signs of psychomotor slowness. This could be explained by the way players were included in this study. Previous research included OR athletes in three different ways: first after a training camp, second by monitoring perceived performance and third by clinical diagnosis. This means that the athletes were included in different stages of the overtraining continuum with symptoms varying in duration and severity. The second explanation is the type of reaction time task used. We choose to use the FPT because it has proven to be sensitive to short term OR after a training camp (Rietjens et al., 2005; Nederhof et al., 2007). Furthermore, this simple task meets the requirements for early detection of OR (Nederhof et al., 2006). This task can be easily implemented within a training schedule, is not too demanding for athletes, and can be performed on a regular personal computer. However, the FPT is not a sport-specific task. Future research should use a sport-specific reaction time task without violating the requirements of a usable marker for OR.

In line with previous literature, subjects produced shorter reaction times after exercise (Davranche & Audiffren, 2004; Davranche, Audiffren, et al., 2006; Davranche et al., 2005; Davranche, Burle, et al., 2006; Lemmink & Visscher, 2005). In addition, the fastest reaction times were performed under the hand and finger cue conditions (Adam, Hommel, & Umiltà, 2003; Rietjens et al., 2005; Nederhof et al., 2007; Nederhof, Visscher, et al., 2008). Given that the uncued condition is the most sensitive for OR (Rietjens et al., 2005; Nederhof et al., 2007), we expected that the soccer players with an elevated heart rate would produce slower reaction times, especially with this condition. We hypothesized that this effect would be enlarged by the facilitating effect of maximal exercise. However, this could not be confirmed.

It could be argued that the soccer players recovered in the week between the submaximal test and the follow-up a week later (Lamberts et al., 2010). However, it should be noted that all players suffered from abnormal heart rate increases for at least a month. Since these players completed the regular training program, full recovery within one week is unlikely. Another explanation may be due to the methodological approach being used. In this study we hypothesized that differences in reaction times would be enlarged by the facilitating effect of maximal exercise in a controlled environment. Therefore, we monitored field test performance and included players in the clinical protocol to assess their reaction time before and after maximal exercise. Since reaction time is partly genetically predisposed (Nederhof et al., 2006) large individual differences were observed that resulted in large standard deviations. This makes a group comparison less suitable. Therefore, future research should focus on reaction time changes within individual players, comparing baseline values to in season reaction times (Nederhof, Visscher, et al., 2008).

Since sport-specific performance was monitored prospectively and clinical inclusion occurred one week after the field test, the physiological status of the athletes was determined adequately. This was confirmed by the disturbed stress–recovery balance and by previous research, in which we found altered hormonal profiles and negative mood state with the same methodological approach (Schmikli et al., 2011). Although there were no significant differences in maximal heart rate and time to exhaustion during the incremental exercise test, the maximal heart rate of the OR soccer players tended to be lower. This is in line with the recently published review of Bosquet, Merkari, Arvisais and Aubert

(2008) who reported that maximal heart rate is decreased during OR.

In this study we evaluated changes in submaximal instead of maximal performances by means of heart rate registration. Firstly, maximal testing on a monthly basis during a whole season interferes too much with the training schedule of coaches (Lamberts & Lambert, 2009). Secondly, with such maximal measurements a lack of motivation can influence performance outcome negatively. However, during a submaximal test procedure one should be aware of additional factors that may influence heart rate responses. It is known that physical and psychological stress as well as dehydration caused by high temperature can increase heart rate (Achten & Jeukendrup, 2003; Esposito et al., 2004). In this study all players were tested after a rest day. The submaximal tests lasted between 9 and 12 minutes and were performed at the beginning of the training. Therefore, effects of physical exhaustion and dehydration by training in hot weather seem unlikely. Although an increase of 5 bpm seems to be a small difference in less controlled conditions for categorization of our groups, variations in heart rate were reported to decrease when submaximal intensity increases (Lamberts & Lambert, 2009). An average heart rate at the time of inclusion was 187 bpm, which corresponds to 85–90% of the maximal heart rate. This intensity indeed showed the least variations (Lamberts & Lambert, 2009). In addition, to exclude incidental increases, players were only included if they presented with abnormal heart rate over two consecutive tests, instead of including after a single test. It turned out that an increase in heart rate of 5 bpm over two consecutive measurements was rather uncommon, since only seven out of 94 players were included. Therefore, our cut-off score of an increase of 5 bpm is significant, especially when a decreased heart rate could be expected as a result of regular training.

We conclude that soccer players with an elevated heart rate lasting at least one month show a disturbed stress–recovery balance, but similar reaction times to maximal exercise. Although reaction time as early marker for OR has potential, this could not be confirmed in our study. We emphasize that research should measure performance over the course of a season to incorporate seasonal variability. Furthermore, a sport-specific reaction time task should be used without violating the requirements of a usable marker for OR.

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References

Achten, J., & Jeukendrup, A. E. (2003). Heart rate monitoring: applications and limitations. *Sports Medicine*, *33*, 517–538.

Adam, J. J., Hommel, B., & Umiltà, C. (2003). Preparing for perception and action (I): The role of grouping in the response-cuing paradigm. *Cognitive Psychology*, *46*, 302–358.

Adam, J. J., Paas, F. G. W. C., Teeken, J. C., van Loon, E. M., van Boxtel, M. P. J., Houx, P. J., & Jolles, J. (1998). Effects of age on performance in a finger-precuing task. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 870–883.

Armstrong, L. E., & VanHeest, J. L. (2002). The unknown mechanism of the overtraining syndrome: clues from depression and psychoneuroimmunology. *Sports Medicine*, *32*, 185–209.

Bosquet, L., Merkari, S., Arvisais, D., & Aubert, A. E. (2008). Is heart rate a convenient tool to monitor over-reaching? A systematic review of the literature. *British Journal of Sports Medicine*, *42*, 709–714.

Brink, M. S., Visscher, C., Arends, S., Zwerver, J., Post, W. J., & Lemmink, K.A.P.M. (2010). Monitoring stress and recovery; new insights for the prevention of injuries and illnesses in elite youth soccer players. *British Journal of Sports Medicine*, *44*, 809–815.

Brink, M. S., Visscher, C., Coutts, A. J., & Lemmink, K. A. P. M. (2010). Changes in perceived stress and recovery in overreached adolescent elite soccer players. *Scandinavian Journal of Medicine & Science in Sports*. doi: 10.1111/j.1600-0838.2010.01237.x. [Epub ahead of print]

Coutts, A. J., & Reaburn, P. (2008). Monitoring changes in rugby league players' perceived stress and recovery during intensified training. *Perceptual and Motor Skills*, *106*, 904–916.

Coutts, A. J., Reaburn, P., Piva, T. J., & Rowsell, G. J. (2007). Monitoring for overreaching in rugby league players. *European Journal of Applied Physiology*, *99*, 313–324.

Davranche, K., & Audiffren, M. (2004). Facilitating effects of exercise on information processing. *Journal of Sports Sciences*, *22*, 419–428.

Davranche, K., Audiffren, M., & Denjean, A. (2006). A distributional analysis of the effect of physical exercise on a choice reaction time task. *Journal of Sports Sciences*, *24*, 323–329.

Davranche, K., Burle, B., Audiffren, M., & Hasbroucq, T. (2005). Information processing during physical exercise: a chronometric and electromyographic study. *Experimental Brain Research*, *165*, 532–540.

Davranche, K., Burle, B., Audiffren, M., & Hasbroucq, T. (2006). Physical exercise facilitates motor processes in simple reaction time performance: An electromyographic analysis. *Neuroscience Letters*, *396*, 54–56.

Esposito, F., Impellizzeri, F. M., Margonato, V., Vanni, R., Pizzini, G., & Veicsteinas, A. (2004). Validity of heart rate as an indicator of aerobic demand during soccer activities in amateur soccer players. *European Journal of Applied Physiology*, *93*, 167–172.

Fry, R. W., Morton, A. R., & Keast, D. (1991a). Overtraining syndrome and the chronic fatigue syndrome: Part 1. *New Zealand Journal of Sports Medicine*, *19*, 48–52.

Fry, R. W., Morton, A. R., & Keast, D. (1991b). Overtraining syndrome and the chronic fatigue syndrome: Part 2. *New Zealand Journal of Sports Medicine*, *19*, 76–77.

Fuller, C. W., Ekstrand, J., Junge, A., Andersen, T. E., Bahr, R., Dvorak, J., Hägglund, M., McCrory, P., & Meeuwisse, W. H. (2006). Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *British Journal of Sports Medicine*, *40*, 193–201.

Jurimae, J., Maestu, J., Purge, P., Jurimae, T., & Soot, T. (2002). Relations among heavy training stress, mood state, and performance for male junior rowers. *Perceptual and Motor Skills*, *95*, 520–526.

Kellmann, M., & Gunther, 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*, 676–683.

Kellmann, M., & Kallus, K. W. (1999). Mood, recovery-stress state and regeneration. In M. Lehman, C. Foster, U. Gastmann, H. Keizer, & J. M. Steinacker (Eds.), *Overload, performance incompetence and regeneration in sport* (pp. 101–117). New York: Kluwer Academic/Plenum publishers.

Kellmann, M., & Kallus, K. W. (2001). *Recovery-stress questionnaire for athletes: User manual*. Champaign, IL: Human Kinetics.

Lamberts, R. P., & Lambert, M. I. (2009). Day-to-day variation in heart rate at different levels of submaximal exertion: implications for monitoring training. *Journal of Strength and Conditioning Research*, *23*, 1005–1010.

Lamberts, R. P., Rietjens, G. J., Tijdink, H. H., Noakes, T. D., & Lambert, M. I. (2010). Measuring submaximal performance parameters to monitor fatigue and predict cycling performance: a case study of a world-class cyclo-cross cyclist. *European Journal of Applied Physiology*, *108*, 183–190.

Lehmann, M., Foster, C., & Keul, J. (1993). Overtraining in endurance athletes: a brief review. *Medicine and Science in Sports and Exercise*, *25*, 854–862.

Lemmink, K. A. P. M., & Visscher, C. (2003). The relationship between the interval shuttle run test and maximal oxygen uptake in soccer players. *Journal of Human Movement Studies*, *45*, 219–232.

Lemmink, K. A. P. M., & Visscher, C. (2005). Effect of intermittent exercise on multiple-choice reaction times of soccer players. *Perceptual and Motor Skills*, *100*, 85–95.

Lemmink, K. A. P. M., Visscher, C., Lambert, M. I., & Lamberts, R. P. (2004). The interval shuttle run test for intermittent sport players: evaluation of reliability. *Journal of Strength and Conditioning Research*, *18*, 821–827.

McMorris, T., Davranche, K., Jones, G., Hall, B., Corbertt, J., & Minter, C. (2009). Acute incremental exercise, performance of a central executive task, and sympathoadrenal system and hypothalamic-pituitary-adrenal axis activity. *International Journal of Psychophysiology*, *72*, 334–340.

Meeusen, R., Duclos, M., Gleeson, M., Steinacker, J., Rietjens, G., & Urhausen, A. (2006). Prevention, diagnosis and treatment of the overtraining syndrome. *European Journal of Sport Science*, *6*, 1–14.

Meeusen, R., Nederhof, E., Buyse, L., Roelands, B., de Schutter, G., & Piacentini, M. F. (2010). Diagnosing overtraining in athletes using the two bout exercise protocol. *British Journal of Sports Medicine*, *44*, 642–648.

Meeusen, R., Piacentini, M. F., Busschaert, B., Buyse, L., Schutter, G. d., & Stray-Gundersen, J. (2004). Hormonal responses in athletes: the use of a two bout exercise protocol to detect subtle differences in (over)training status. *European Journal of Applied Physiology*, *91*, 140–146.

Nederhof, E., Brink, M. S., & Lemmink, K. A. P. M. (2008). Reliability and validity of the Dutch Recovery Stress Questionnaire for athletes. *International Journal of Sport Psychology*, *39*, 301–311.

Nederhof, E., Lemmink, K. A. P. M., Visscher, C., Meeusen, R., & Mulder, T. (2006). Psychomotor speed: possibly a new marker for overtraining syndrome. *Sports Medicine*, *36*, 817–828.

Nederhof, E., Lemmink, K. A. P. M., Zwerver, J., & Mulder, T. (2007). The effect of high load training on psychomotor speed. *International Journal of Sports Medicine*, *28*, 595–601.

Nederhof, E., Visscher, C., & Lemmink, K.A.P.M. (2008). Psychomotor speed is related to perceived performance in rowers. *European Journal of Sport Science*, *8*, 259–265.

Nederhof, E., Zwerver, J., Brink, M. S., Meeusen, R., & Lemmink, K. A. P. M. (2008). Different diagnostic tools in nonfunctional overreaching. *International Journal of Sports Medicine*, *29*, 590–597.

Rietjens, G. J., Kuipers, H., Adam, J. J., Saris, W. H., van Breda, E., van Hamont, D., & Keizer, H. A. (2005). Physiological, biochemical and psychological markers for overreaching: Early markers for overreaching. *International Journal of Sports Medicine*, *26*, 16–26.

Schmikli, S. L., Brink, M. S., de Vries, W. R., & Backx, F. J. G. (2011). Can we detect non-functional overreaching in young elite soccer players and middle-long distance runners using field performance tests? *British Journal of Sports Medicine*, *45*, 631–636.

Uusitalo, A. L. T. (2001). Overtraining: making a difficult diagnosis and implementing targeted treatment. *The Physician and Sportsmedicine*, *29*, 35–50.

Wilmore, J. H., Stanforth, P. R., Gagnon, J., Leon, A. S., Rao, D. C., Skinner, J. S., & Bouchard, C. (1996). Endurance exercise training has a minimal effect on resting heart rate: the HERITAGE Study. *Medicine and Science in Sports and Exercise*, *28*, 829–835.