Bundesinstitut
für Sportwissenschaft

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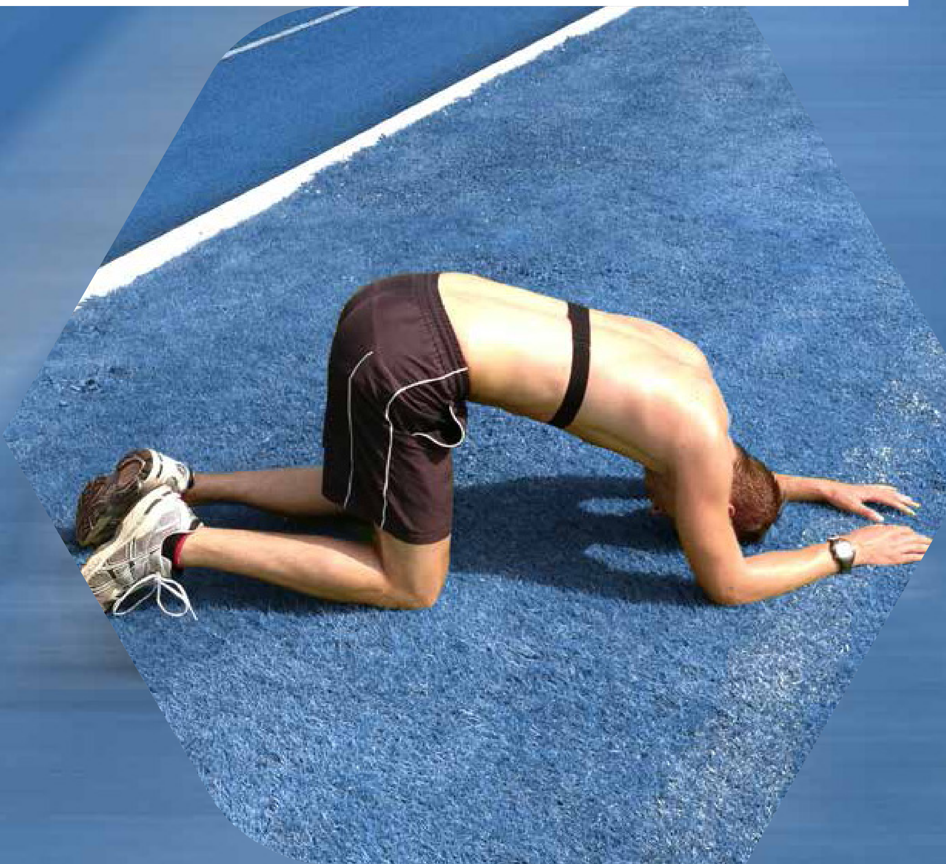
REGman -
Regenerationsmanagement im Spitzensport

(REGman - Management of Regeneration in Elite Sports)

Publikationen / Abstracts



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Weiterführende Informationen zum Projekt:
www.regman.org

Publikationen

REGman
REGENERATIONSMANAGEMENT IM SPORT

De Paula Simola, R.A., Harms, N., Raeder, C., Kellmann, M., Meyer, T., Pfeiffer, M., & Ferrauti, A. (2015). Assessment of neuromuscular function after different strength training protocols using tensiomyography. Journal of Strength and Conditioning Research, 29 (5), 507-515

The purpose of the study was to analyse tensiomyography (TMG) sensitivity to changes in muscle force and neuromuscular function of the muscle rectus femoris (RF) using TMG muscle properties after five different lower-limb strength training protocols (MS = Multiple Sets; DS = Drop Sets; EO = Eccentric Overload; FW = Flywheel; PL = Plyometrics). After baseline measurements, 14 male strength trained athletes completed one squat training protocol per week over a five-week period in a randomized controlled order. Maximal voluntary isometric contraction (MVIC), TMG measurements of maximal radial displacement of the muscle belly (Dm), contraction time between 10 and 90% of Dm (Tc) as well as mean muscle contraction velocities from the beginning until 10% (V10), and 90% of Dm (V90) were analysed up to 0.5 hours (post-train), 24 hours (post-24) and 48 hours (post-48) after the training interventions. Significant ANOVA main effects for measurement points were found for all TMG contractile properties and MVIC ($p < 0.01$). Dm and V10 post-train values were significantly lower after protocols DS and FW compared to protocol PL ($p = 0.032$ and 0.012, respectively). Dm, V10, and V90 decrements correlated significantly to the decreases in MVIC ($r = 0.64$-0.67; $p < 0.05$). Some TMG muscle properties are sensitive to changes in muscle force and different lower-limb strength training protocols lead to changes in neuromuscular function of RF. In addition, those protocols involving high and eccentric load, and a high total time under tension may induce higher changes in TMG muscle properties.

De Paula Simola, R.A., Harms, N., Raeder, C., Kellmann, M., Meyer, T., Pfeiffer, M., & Ferrauti, A. (2015). Tensiomyography reliability and prediction of changes in muscle force following heavy eccentric strength exercise using muscle mechanical properties. Sports Technology, 8, 58-66

The current study involved the completion of two distinct experiments. Experiment 1 analyzed the inter-day reliability of tensiomyography (TMG) muscle mechanical properties based on the amplitude of the muscle belly radial deformation, the time it takes to occur, and its velocity under maximal and submaximal stimuli, in the muscles rectus femoris, biceps femoris, and gastrocnemius lateralis, from 20 male sport students. Experiment 2 investigated whether changes in maximal voluntary isometric contraction (MVIC) could be predicted based on changes in TMG properties following 24 h after different squat training protocols (MS = multiple sets; DS = drop sets; EO = eccentric overload; FW = flywheel; PL = plyometrics) executed by 14 male strength trained athletes. Maximal electrical stimulation exhibited higher level of reliability. In most of the cases, TMG properties Tc, Td, Dm, V10, and V90 showed ICC scores >.8 and CV <10%. Simple linear regression analysis revealed that changes in Dm, V10, and V90 correlated with changes in MVIC following EO at r = .705, .699, and .695, respectively. TMG is a reliable method to assess muscle mechanical properties particularly within maximal stimuli and can be used for prediction of changes in MVIC following heavy eccentric strength exercises.

De Paula Simola, R.A., Raeder, C., Wiewelhove, T., Kellmann, M., Meyer, T., Pfeiffer, M., & Ferrauti, A. (2016). Muscle mechanical properties of strength and endurance athletes and changes after one week of intensive training. Journal of Electromyography and Kinesiology, 30, 73-80

The study investigates whether tensiomyography (TMG) is sensitive to differentiate between strength and endurance athletes, and to monitor fatigue after either one week of intensive strength (ST) or endurance (END) training. Fourteen strength (24.1±2.0years) and eleven endurance athletes (25.5±4.8years) performed an intensive training period of 6days of ST or END, respectively. ST and END groups completed specific performance tests as well as TMG measurements of maximal radial deformation of the muscle belly (Dm), deformation time between 10% and 90% Dm (Tc), rate of deformation development until 10% Dm (V10) and 90% Dm (V90) before (baseline), after training period (post1), and after 72h of recovery (post2). Specific performance of both groups decreased from baseline to post1 ($P<0.05$) and returned to baseline values at post2 ($P<0.05$). The ST group showed higher countermovement jump ($P<0.05$) and shorter Tc ($P<0.05$) at baseline. After training, Dm, V10, and V90 were reduced in the ST ($P<0.05$) while TMG changes were less pronounced in the END. TMG could be a useful tool to differentiate between strength and endurance athletes, and to monitor fatigue and recovery especially in strength training.

Hecksteden, A., Leidinger, P., Backes, C., Rheinheimer, S., Pfeiffer, M., Ferrauti, A., Kellmann, M., Sedaghat, F., Meder, B., Meese, E., Meyer, T., Keller, A.: miRNAs and sports: tracking training status and potentially confounding diagnoses. J Transl Med 14, 2016: 219. DOI: 10.1186/s12967-016-0974-x

BACKGROUND:
The dependency of miRNA abundance from physiological processes such as exercises remains partially understood. We set out to analyze the effect of physical exercises on miRNA profiles in blood and plasma of endurance and strength athletes in a systematic manner and correlated differentially abundant miRNAs in athletes to disease miRNAs biomarkers towards a better understanding of how physical exercise may confound disease diagnosis by miRNAs.

METHODS:
We profiled blood and plasma of 29 athletes before and after exercise. With four samples analyzed for each individual we analyzed 116 full miRNomes. The study set-up enabled paired analyses of individuals. Affected miRNAs were investigated for known disease associations using network analysis.

RESULTS:
MiRNA patterns in blood and plasma of endurance and strength athletes vary significantly with differences in blood outreaching variations in plasma. We found only moderate differences between the miRNA levels before training and the RNA levels after training as compared to the more obvious variations found between strength athletes and endurance athletes. We observed significant variations in the abundance of miR-140-3p that is a known circulating disease markers (raw and adjusted p value of 5 × 10(-12) and 4 × 10(-7)). Similarly, the levels of miR-140-5p and miR-650, both of which have been reported as makers for a wide range of human pathologies significantly depend on the training mode. Among the most affected disease categories we found acute myocardial infarction. MiRNAs, which are up-regulated in endurance athletes inhibit VEGFA as shown by systems biology analysis of experimentally validated target genes.

CONCLUSION:
We provide evidence that the mode and the extent of training are important confounding factors for a miRNA based disease diagnosis.

Hecksteden, A., Pitsch, W., Julian, R., Pfeiffer, M., Kellmann, M., Ferrauti, A., Meyer, T.: A new method to individualize monitoring of muscle recovery in athletes. Int J Sports Physiol Perform: im Druck

PURPOSE:
Assessment of muscle recovery is essential for the daily fine-tuning of training load in competitive sports, but individual differences may limit the diagnostic accuracy of group-based reference ranges. We report an attempt to develop individualized reference ranges using a Bayesian approach comparable to that developed for the athlete biological passport.

METHODS:
Urea and creatine kinase (CK) were selected as indicators of muscle recovery. For each parameter, prior distributions and repeated measures standard deviations were characterized based on data of 883 squad athletes (1758 data points, 1-8 per athlete, years 2013-2015). Equations for the individualization procedure were adapted from previous material to allow for discrimination of 2 physiological states (recovered; non-recovered). Evaluation of classificatory performance was carried out using data from 5 consecutive weekly microcycles in 14 elite junior swimmers and triathletes. Blood samples were collected every Monday (recovered) and Friday according to the repetitive weekly training schedule over five weeks. On the group level, changes in muscle recovery could be confirmed by significant differences in urea, CK and validated questionnaires. Group-based reference ranges were derived from that same dataset to avoid overestimating the potential benefit of individualization.

RESULTS:
For CK error rates were significantly lower with individualized classification (p vs. group-based: test-pass error rate: $p=0,008$; test-fail error rate: $p<0,001$). For urea numerical improvements in error rates failed to reach significance.

CONCLUSIONS:
Individualized reference ranges seem to be a promising tool to improve accuracy of monitoring muscle recovery. Investigating application to a larger panel of indicators is warranted.

Hecksteden, A., Skorski, S., Schwindling, S., Hammes, D., Pfeiffer, M., Kellmann, M., Ferrauti, A., Meyer, T.: Blood-borne Markers of Fatigue in Competitive Athletes – Results from Simulated Training Camp. PLOS ONE, 11, 2016: e0148810. DOI: 10.1371/journal.pone.0148810

Assessing current fatigue of athletes to fine-tune training prescriptions is a critical task in competitive sports. Blood-borne surrogate markers are widely used despite the scarcity of validation trials with representative subjects and interventions. Moreover, differences between training modes and disciplines (e.g. due to differences in eccentric force production or calorie turnover) have rarely been studied within a consistent design. Therefore, we investigated blood-borne fatigue markers during and after discipline-specific simulated training camps. A comprehensive panel of blood-born indicators was measured in 73 competitive athletes (28 cyclists, 22 team sports, 23 strength) at 3 time-points: after a run-in resting phase (d 1), after a 6-day induction of fatigue (d 8) and following a subsequent 2-day recovery period (d 11). Venous blood samples were collected between 8 and 10 a.m. Courses of blood-borne indicators are considered as fatigue dependent if a significant deviation from baseline is present at day 8 (Δfatigue) which significantly regresses towards baseline until day 11 (Δrecovery). With cycling, a fatigue dependent course was observed for creatine kinase (CK; Δfatigue 54±84 U/l; Δrecovery -60±83 U/l), urea (Δfatigue 11±9 mg/dl; Δrecovery -10±10 mg/dl), free testosterone (Δfatigue -1.3±2.1 pg/ml; Δrecovery 0.8±1.5 pg/ml) and insulin linke growth factor 1 (IGF-1; Δfatigue -56±28 ng/ml; Δrecovery 53±29 ng/ml). For urea and IGF-1 95% confidence intervals for days 1 and 11 did not overlap with day 8. With strength and high-intensity interval training, respectively, fatigue-dependent courses and separated 95% confidence intervals were present for CK (strength: Δfatigue 582±649 U/l; Δrecovery -618±419 U/l; HIIT: Δfatigue 863±952 U/l; Δrecovery -741±842 U/l) only. These results indicate that, within a comprehensive panel of blood-borne markers, changes in fatigue are most accurately reflected by urea and IGF-1 for cycling and by CK for strength training and team sport players.

Hitzschke, B., Holst, T., Ferrauti, A., Meyer, T., Pfeiffer, M. & Kellmann, M. (2016). Entwicklung des Akutmaßes zur Erfassung von Erholung und Beanspruchung im Sport. Diagnostica, 62 (4), 212-226

The sport-specific Acute Recovery and Stress Scale (ARSS) was developed within the collaborative research project REGman, which is sponsored by the Federal Institute of Sport Science. Following an expert survey, the initial questionnaire consisting of 32 adjectives was completed by sport students (N = 257). Based on the results of an exploratory factor and a reliability analysis, models for recovery and for stress were created, respectively. For verification of these models by confirmatory factor analysis, the revised version was tested on a group of performance-oriented athletes (N = 429). Afterward, the version was slightly modified and validated by a group of high-level athletes (N = 574). The confirmatory factor analysis indicated good-fit indices as well as scale homogeneity. Furthermore, the first indications of construct validity were obtained, as shown by the correlations with the convergent procedures Recovery-Stress Questionnaire for Athletes (RESTQ-Sport) and Delayed-Onset Muscle Soreness (DOMS).

Hitzschke, B., Kölling, S., Ferrauti, A., Meyer, T., Pfeiffer, M. & Kellmann, M. (2015). Entwicklung der Kurzskala zur Erfassung von Erholung und Beanspruchung im Sport (KEB). Zeitschrift für Sportpsychologie, 22, 146-161

A short version (Short Recovery and Stress Scale for Sport [SRSS]) of the Acute Recovery and Stress Scale for Sport (ARSS) was developed to satisfy the request for an economic, valid, and change-sensitive psychometric instrument to quantify recovery and stress. After a four-stage development and validation process, including an exploratory calculation and confirmatory verification of the factors of the ARSS, the SRSS was derived with eight items. It was possible to calculate an excellent homogeneity range, moderate intercorrelation, and hypothetical conformity correlations to the ARSS. The SRSS shows a content-matching correlation pattern to the ARSS in reference to the convergent method Recovery-Stress Questionnaire for Athletes (RESTQ-Sport) and the visual analogue scale for Delayed-Onset Muscle Soreness (DOMS). In a monitoring session during the training camp of the German junior national field hockey team, the change sensitiveness of the SSRS was proved and a concurring result pattern in reference to the ARSS, the RESTQ-Sport, and the DOMS was demonstrated.

Julian, R., Meyer, T., Fullagar, H.H.K., Skorski, S., Pfeiffer, M., Kellmann, M., Ferrauti, A., Hecksteden, A.: Individual patterns in blood-borne indicators of fatigue - trait or chance. J Strength Cond Res 31, 2017: 608-619

Blood-borne markers of fatigue such as creatine kinase (CK) and urea (U) are widely used to fine-tune training recommendations. However, predictive accuracy is low. A possible explanation for this dissatisfactory characteristic is the propensity of athletes to react to different patterns of fatigue indicators (e.g., predominantly muscular [CK] or metabolic [U]). The aim of the present trial was to explore this hypothesis by using repetitive fatigue-recovery cycles. A total of 22 elite junior swimmers and triathletes (18 ± 3 years) were monitored for 9 weeks throughout 2 training phases (low-intensity, high-volume [LIHV] and high-intensity, low-volume [HILV] phases). Blood samples were collected each Monday (recovered) and Friday (fatigued) morning. From measured values of CK, U, free-testosterone (FT), and cortisol (C) as determined in the rested and fatigued state, respectively, Monday-Friday differences (Δ) were calculated and classified by magnitude before calculation of ratios (ΔCK/ΔU and ΔFT/ΔC). Coefficient of variation (CV) was calculated as group-based estimates of reproducibility. Linear mixed modeling was used to differentiate inter- and intraindividual variability. Consistency of patterns was analyzed by comparing with threshold values (<0.9 or >1.1 for all weeks). Reproducibility was very low for fatigue-induced changes (CV ≥ 100%) with interindividual variation accounting for 45-60% of overall variability. Case-wise analysis indicated consistent ΔCK/ΔU patterns for 7 individuals in LIHV and 7 in HILV; 5 responded consistently throughout. For ΔFT/ΔC the number of consistent patterns was 2 in LIHV and 3 in HILV. These findings highlight the potential value of an individualized and multivariate approach in the assessment of fatigue.

Kölling, S., Endler, S., Ferrauti, A., Meyer, T. & Kellmann, M. (2016). Comparing Subjective with Objective Sleep Parameters via Multi-Sensory Actigraphy in Physical Education Students. Behavioral Sleep Medicine, 14, 389-405

This study compared subjective with objective sleep parameters among 72 physical education students. Furthermore, the study determined whether 24-hr recording differs from nighttime recording only. Participants wore the SenseWear Armband™ for three consecutive nights and kept a sleep log. Agreement rates ranged from moderate to low for sleep onset latency (ICC D 0.39 to 0.70) and wake after sleep onset (ICC D 0.22 to 0.59), while time in bed (ICC D 0.93 to 0.95) and total sleep time (ICC D 0.90 to 0.92) revealed strong agreement during this period. Comparing deviations between 24-hr wearing time (n D 24) and night-only application (n D 20) revealed no statistical difference ($p > 0.05$). As athletic populations have yet to be investigated for these purposes, this study provides useful indicators and practical implications for future studies.

Kölling, S., Ferrauti, A., Pfeiffer, M., Meyer, T. & Kellmann, M. (2016). Sleep in Sports: A Short Summary of Alterations in Sleep/Wake Patterns and the Effects of Sleep Loss and Jet-Lag. Deutsche Zeitschrift für Sportmedizin, 67, 35-38

This review article aims to summarise general aspects regarding sleep and sports. It is generally assumed that sleep is a basic requirement for physiological and psychological recovery, whereas it appears that sleep of elite athletes is highly influenced by training stimuli and external as well as internal factors. Studies about sleep deprivation and restricted sleep indicate the importance for cognitive functions as well as mood and behavioural aspects. Effects on performance parameters are not reported as consistently. In contrast to sleep restriction, extending sleep for several nights might lead to improvements in performance, mood, and alertness. In terms of intercontinental travel, jet-lag might be an issue for elite athletes. Although a few studies indicate that effects on athletic performance might not be present, sleep, mood and some physiological measures are affected due to shift in time zones. Simple strategies can be applied to enhance adaptation to the destination and diminish jet-lag symptoms.

Kölling, S., Hitzschke, B., Holst, T., Ferrauti, A., Meyer, T., Pfeiffer, M. & Kellmann, M. (2015). Validity of the Acute Recovery and Stress Scale – Training Monitoring of the German Junior National Field Hockey Team. International Journal of Sports Science & Coaching, 10, 529-542

The aim of the present study was to examine the sensitivity of the Acute Recovery and Stress Scale (ARSS). This new psychometric questionnaire was developed to assess the physical, mental, emotional, and overall recovery and stress states of athletes. During a five-day field hockey training camp of the German Junior National Field Hockey Team (n = 25) the ARSS was administered every morning and evening. The study indicated swift reactions of the scores of the physical and general factors as well as stability of scores for the emotional factors in accordance with the training schedule. The straining effect of the camp was best reflected by the adaptations of the scales Physical Performance Capability ($F_{2.9, 60.3} = 10.0$, $p < 0.001$) and Muscular Stress ($F_{4, 84} = 16.7$, $p < 0.001$). The results support the ability of the ARSS to monitor recovery-stress (im-)balances in this sample. Thus, the questionnaire has shown to be a sensitive and practical tool that might be suitable for elite sport settings.

Kölling, S., Steinacker, J.M., Pfeiffer, M., Ferrauti, A., Meyer, T. & Kellmann, M. (2016). The Longer the Better: Sleep/Wake Patterns during Preparation of the World Rowing Junior Championships. Chronobiology International, 33(1), 73-84

Recovery is essential for high athletic performance, and therefore especially sleep has been identified as a crucial source for physical and psychological well-being. However, due to early morning trainings, which are general practice in many sports, athletes are likely to experience sleep restrictions. Therefore, this study investigated the sleep–wake patterns of 55 junior national rowers (17.7 ± 0.6 years) via sleep logs and actigraphy during a four-week training camp. Recovery and stress ratings were obtained every morning with the Short Recovery and Stress Scale on a 7-point Likert-type scale ranging from 0 (does not apply at all) to 6 (fully applies). The first training session was scheduled for 6:30 h every day. With two to four training sessions per day, the training load was considerably increased from athletes' home training. Objective sleep measures ($n = 14$) revealed less total sleep time (TST) in the first two weeks (409.6 ± 19.1 and 416.0 ± 16.3 min), while training volume and intensity were higher. In the second half of the camp, less training sessions were implemented, more afternoons were training free and TSTs were longer (436.3 ± 15.8 and 456.9 ± 25.7 min). A single occasion of 1.5-h delayed bedtime and usual early morning training (6:30 h) resulted in reduced ratings of Overall Recovery (OR) ($M = 3.3 \pm 1.3$) and greater Negative Emotional State (NES) ($M = 1.3 \pm 1.2$, $p < .05$), which returned to baseline on the next day. Following an extended night due to the only training-free day, sleep-offset times were shifted from ~5:30 to ~8:00 h, and each recovery and stress score improved ($p < .01$). Moreover, subjective ratings of the first six days were summarised as a baseline score to generate reference data as well as to explore the association between sleep and recovery. Intercorrelations of these sleep parameters emphasized the relationship between restful sleep and falling asleep quickly ($r = .34$, $p < .05$) as well as few awakenings ($r = .35$, $p < .05$). Overall, the findings highlight the impact of sleep on subjective recovery measures in the setting of a training camp. Providing the opportunity of extended sleep (and a day off) seems the most simple and effective strategy to enhance recovery and stress-related ratings.

Kölling, S., Treff, G., Winkert, K., Ferrauti, A., Meyer, T., Pfeiffer, M. & Kellmann, M. (in Druck). The Effect of Westward Travel Across Five Time-Zones on Sleep and Subjective Jet-Lag Ratings in Athletes before and during the 2015's World Rowing Junior Championships. Journal of Sports Sciences. DOI: 10.1080/02640414.2016.1265141

This study examined sleep-wake habits and subjective jet-lag ratings of 55 German junior rowers ($n = 30$ male, 17.8 ± 0.5 years) before and during the World Rowing Junior Championships 2015 in Rio de Janeiro, Brazil. Athletes answered sleep logs every morning, and Liverpool John Moore's University Jet-Lag Questionnaires each evening and morning. Following an 11-h westward flight with 5-h time shift, advanced bedtimes (−1 h, $P < .001$, $\eta p2 = 0.68$), reduced sleep onset latency ($P = .002$, $\eta p2 = 0.53$) and increased sleep duration ($P < .001$, $\eta p\ 2 = 0.60$) were reported for the first two nights. Jetlag symptoms peaked upon arrival but were still present after 6 days. Sleep quality improved ($P < .001$, $\eta p\ 2 = 0.31$) as well as some scales of the Recovery-Stress Questionnaire for Athletes. Participation was successful as indicated by 11 of 13 top 3 placings. Overall, the initial desynchronisation did not indicate negative impacts on competition performance. As travel fatigue probably had a major effect on perceptual decrements, sleep during travel and time to recover upon arrival should be emphasised. Coaches and practitioners should consider higher sleep propensity in the early evening by scheduling training sessions and meetings until the late afternoon.

Kölling, S., Wiewelhove, T., Raeder, C., Endler, S., Ferrauti, A., Meyer, T. & Kellmann, M. (2016). Sleep Monitoring of a Six-Day Microcycle in Strength and High-Intensity Training. European Journal of Sport Science, 16, 507-515

This study examined the effect of microcycles in eccentric strength and high-intensity interval training (HIT) on sleep parameters and subjective ratings. Forty-two well-trained athletes (mean age 23.2 ± 2.4 years) were either assigned to the strength (n = 21; mean age 23.6 ± 2.1 years) or HIT (n = 21; mean age 22.8 ± 2.6 years) protocol. Sleep monitoring was conducted with multi-sensor actigraphy (SenseWear Armband™, Bodymedia, Pittsburg, PA, USA) and sleep log for 14 days. After a five-day baseline phase, participants completed either eccentric accented strength or high-intensity interval training for six days, with two training sessions per day. This training phase was divided into two halves (part 1 and 2) for statistical analyses. A three-day post phase concluded the monitoring. The Recovery-Stress Questionnaire for Athletes was applied at baseline, end of part 2, and at the last post-day. Mood ratings were decreased during training, but returned to baseline values afterwards in both groups. Sleep parameters in the strength group remained constant over the entire process. The HIT group showed trends of unfavourable sleep during the training phase (e.g., objective sleep efficiency at part 2: mean = 83.6 ± 7.8%, F3,60 = 2.57, P = 0.06, g2p = 0.114) and subjective improvements during the post phase for awakenings (F3,60 = 2.96, P = 0.04, g2 p = 0.129) and restfulness of sleep (F3,60 = 9.21, P < 0.001, g2p = 0.315). Thus, the HIT protocol seems to increase higher recovery demands than strength training, and sufficient sleep time should be emphasised and monitored.

Meyer, T., Kellmann, M., Ferrauti, A., Pfeiffer, M., Faude, O.: Die Messung von Erholtheit und Regenerationsbedarf im Fußball. Dtsch Z Sportmed 64, 2013: 28-34

In elite football, improved regeneration is being considered more and more as relevant to performance enhancement. This is particularly true in light of a dense schedule of competition and other obligations. But to determine individual regenerative requirements, it is necessary to measure the degree of recovery that has been reached since the last training and/or competition (or in the long-term constellation of additive loads). Such an indicator of the recovery state should fulfill the normal requirements for testing procedures: objectivity, reliability and validity. In addition, its determination should not be too time-consuming and too expensive. Finally, the determination itself must not be tiresome. Considering all these criteria, there is no single optimal indicator which integratively covers all levels of fatigue. While laboratory values and simple motor tests are objective and cheap, they cover only a part of football-specific requirements. Psychometric scales integrate several levels of fatigue but can be seen through and, thus, potentially manipulated by players. Some supplementary methods, as well as some rather experimental laboratory values, need further evaluation. Therefore, it will be a target of future scientific efforts to create a battery of simple motor tests, laboratory values, psychometric scales and supplementary methods (e.g. parameters from measurements of resting heart rate) which covers the demands of regular elite football training. For this purpose, cooperation with players, trainers and other team staff of professional teams is indispensible.

Nässi, A., Ferrauti, A., Meyer, T., Pfeiffer, M. & Kellmann, M. (2017). Development of Two Short Measures for Recovery and Stress in Sport. European Journal of Sport Science, 17(7), 894-903

The Acute Recovery and Stress Scale (ARSS) and the Short Recovery and Stress Scale were first established in German for the purposes of monitoring athletes' current recovery-stress states in an economical and multidimensional manner. The aim of this paper is to document the development and initial validation of the English versions of these two psychometric monitoring tools. A total of 267 English-speaking athletes from a variety of team and individual sports participated in the study. The English versions demonstrated satisfactory internal consistency for both instruments (Cronbach α of .74–.89). Furthermore, good model fit was found for the eight scales of the ARSS, matching the structure and results of the German counterparts. Correlations among and between the scales reciprocate the theoretical constructs of stress and recovery, supporting the construct validity of the scales. Correlation coefficients within stress and recovery ranged between rs = .29 and .68. The correlations between stress and recovery varied between rs = −.29 and −.64. These constructs were further supported by correlations with the scores of the Recovery-Stress Questionnaire for Athletes, thereby showing convergent validity. The findings demonstrate initial validity and reliability of the two measures and reflect the results of the German versions. However, further research is needed before applying these scales in practical settings.

Nässi, A., Ferrauti, A., Meyer, T., Pfeiffer, M. & Kellmann, M. (in Druck). Psychological Tools used for Monitoring Training Responses of Athletes. Performance Enhancement & Health. DOI: 10.1016/j.peh.2017.05.001

Monitoring athletes' responses to training and other life stressors is crucial for implementing favourable training routines and achieving optimal performances. The purpose of this review is to provide an overview and evaluation of current psychological tools used in training contexts among athletes. The instruments discussed include the Profile of Mood States (POMS), the Emotional Recovery Questionnaire (EmRecQ), the Total Quality Recovery (TQR) scale, the Daily Analyses of Life Demands for Athletes(DALDA), the Recovery-Stress Questionnaire for Athletes (RESTQ-Sport), the Acute Recovery and Stress Scale (ARSS), the Short Recovery and Stress Scale (SRSS), and the Multi-Component Training Distress Scale (MTDS). Each measure has been shown to deliver valuable information for athletes and coaches regarding individual responses to training. These responses are measured by observing changes in mood, emotions, perceived stress and recovery, and sleep quality. Practitioners need to consider the appropriateness of each psychological tool in the context of their particular group. Regardless of which methods are employed, care should be taken to employ measurement in a systematic manner, provide timely feedback, and consider frequency as not to burden athletes too much. While psychological measures are an important part of avoiding maladaptive training responses, performance and physiological changes also need to be taken into account.

Pelka, M., Ferrauti, A., Meyer, T., Pfeiffer, M. & Kellmann, M. (2017). How Does a Short, Interrupted Recovery Break Affect Performance and How is it Assessed? A Study on Acute Effects. International Journal of Sports Physiology and Performance, 12 (Suppl. 2), S. 2114 – S. 2121

A recovery process with optimal prerequisites that is interrupted is termed disrupted recovery. Whether this process has an influence on performance-related factors needs to be investigated. Therefore, the aim of this study was to examine how a short disturbance of a recovery phase is assessed and whether subsequent repeated-sprint performance is affected by it. A quasi experimental 2 × 2-factor crossover design with 34 sport-science undergraduate students (age 20.3 ± 2.1 y) was applied. Factors were the type of intervention (power nap vs systematic breathing; between-subjects) and the experimental condition (disturbed vs nondisturbed break; within-subject). Repeated-sprint performance was measured through 6 × 4-s sprint protocols (with 20-s breaks) before and after a 25-min recovery break on 2 test days. Subjective evaluation of the interventions was measured through the Short Recovery and Stress Scale and a manipulation check assessing whether participants experienced the recovery phase as efficacious and pleasant. Regarding the objective data, no significant difference between sprint performances in terms of average peak velocity (m/s) on the treadmill was found. The manipulation check revealed that disturbed conditions were rated significantly lower than regular conditions in terms of appreciation, $t31 = 3.09$, $P = .01$. Short disturbances of recovery do not seem to affect subsequent performance; nevertheless, participants assessed disturbed conditions more negatively than regular conditions. In essence, the findings indicate a negligible role of short interruptions on an objective level. Subjectively, they affected the performance-related assessment of the participants and should be treated with caution.

Pelka, M., Heidari, J., Ferrauti, A., Meyer, T., Pfeiffer, M. & Kellmann, M. (2016). Relaxation Techniques in Sports: A Systematic Review on Acute Effects on Performance. Performance Enhancement & Health, 5(2), 47-59

OBJECTIVES:
The aim was to provide an overview on the current state of research on acute effects of relaxation techniques in sports.

DESIGN:
A systematic review of randomized controlled trials was conducted.

METHODS:
PubMed, MEDLINE, PsycINFO, and SPORTDiscus were searched until August 2014. Additionally, reference lists of retrieved articles and relevant reviews were hand searched. To be included articles had to examine the effects of relaxation techniques on performance in sports. Furthermore, they had to be published in English, in a peer-reviewed journal, available full text online, and designed as either treatment outcome, clinical trial, and/or randomized controlled trial. The dependent variable had to be a measure of athletic performance.

RESULTS:
Of the 8,501 articles retrieved after the databased literature search, 21 studies were included in the systematic review. Nine trials dealt solely with somatic relaxation techniques, five with cognitive techniques, and seven trials examined both branches within single studies. Biofeedback and hypnosis were found to be the most effective techniques over a range of performance measures.

CONCLUSIONS:
This review showed that biofeedback and hypnosis can positively influence performance throughout different outcome variables consistently. On the contrary, other techniques that were proven effective in clinical environments did not show consistent results. However, results have to be treated with caution because of considerable lack of quality of some of the trials. Future studies need to consider the methodological flaws as well as the highly individual nature of relaxation techniques.

Pelka, M., Kölling, S., Ferrauti, A., Meyer, T., Pfeiffer, M. & Kellmann, M. (2017). Psychological Relaxation between Two Physical Tasks. Journal of Sports Sciences, 35, 216-223

The concept of recovery strategies includes various ways to achieve a state of well-being, prevent underrecovery syndromes from occurring and re-establish pre-performance states. A systematic application of individualised relaxation techniques is one of those. Following a counterbalanced cross-over design, 27 sport science students (age 25.22 ± 1.08 years; sports participation 8.08 ± 3.92 h/week) were randomly assigned to series of progressive muscle relaxation, systematic breathing, power nap, yoga, and a control condition. Once a week, over the course of five weeks, their repeated sprint ability was tested. Tests (6 sprints of 4 s each with 20 s breaks between them) were executed on a non-motorised treadmill twice during that day intermitted by 25 min breaks. RM-ANOVA revealed significant interaction effects between the relaxation conditions and the two sprint sessions with regard to average maximum speed over all six sprints, $F(4,96) = 4.06$, $P = 0.004$, $\eta 2P = 0.15$. Post-hoc tests indicated that after systematic breathing interventions, $F(1,24) = 5.02$, $P = 0.033$, $\eta 2P = 0.18$, participants performed significantly better compared to control sessions. As the focus of this study lied on basic mechanisms of relaxation techniques in sports, this randomised controlled trial provides us with distinct knowledge on their effects, i.e., systematic breathing led to better performances, and therefore, seems to be a suited relaxation method during high-intensity training.

Poppendieck, W., Ferrauti, A., Kellmann, M., Pfeiffer, M., Wegmann, M., Meyer, T.: Massage and Performance Recovery: A Meta-Analytical Review. Sports Med 46, 2016: 183-204

BACKGROUND:
Post-exercise massage is one of the most frequently applied interventions to enhance recovery of athletes. However, evidence to support the efficacy of massage for performance recovery is scarce. Moreover, it has not yet been concluded under which conditions massage is effective.

OBJECTIVE:
The objective of this study was to perform a systematic review and meta-analysis of the available literature on massage for performance recovery.

METHODS:
We conducted a structured literature search and located 22 randomized controlled trials. These were analysed with respect to performance effects and various characteristics of the study design (type and duration of massage, type of exercise and performance test, duration of recovery period, training status of subjects).

RESULTS:
Of the 22 studies, 5 used techniques of automated massage (e.g., vibration), while the other 17 used classic manual massage. A tendency was found for shorter massage (5-12 min) to have larger effects (+6.6%, $g = 0.34$) than massage lasting more than 12 min (+1.0%, $g = 0.06$). The effects were larger for short-term recovery of up to 10 min (+7.9%, $g = 0.45$) than for recovery periods of more than 20 min (+2.4%, $g = 0.08$). Although after high-intensity mixed exercise, massage yielded medium positive effects (+14.4%, $g = 0.61$), the effects after strength exercise (+3.9%, $g = 0.18$) and endurance exercise (+1.3%, $g = 0.12$) were smaller. Moreover, a tendency was found for untrained subjects to benefit more from massage (+6.5%, $g = 0.23$) than trained athletes (+2.3%, $g = 0.17$).

CONCLUSION:
The effects of massage on performance recovery are rather small and partly unclear, but can be relevant under appropriate circumstances (short-term recovery after intensive mixed training). However, it remains questionable if the limited effects justify the widespread use of massage as a recovery intervention in competitive athletes.

Raeder, C., Wiewelhove, T., De Paula Simola, R.A., Kellmann, M., Meyer, T., Pfeiffer, M., & Ferrauti, A. (2016). Assessment of fatigue and recovery in male and female athletes after 6 days of intensified strength training. Journal of Strength and Conditioning Research, 30 (12), 3412-3427

This study aimed to analyze changes of neuromuscular, physiological, and perceptual markers for rou-tine assessment of fatigue and recovery in high-resistance strength training. Fourteen male and 9 female athletes participated in a 6-day intensified strength training microcycle (STM) designed to purposefully over-reach. Maximal dynamic strength (estimated 1 repetition maximum [1RMest]; criterion measure of fatigueand recovery); maximal voluntary isometric strength (MVIC); countermovement jump (CMJ) height; multiple rebound jump (MRJ) height; jump efficiency (reactive strength index, RSI); muscle contractile properties using tensiomyography including muscle displacement (Dm), delay time (Td), contraction time (Tc), and contraction velocity (V90); serum concentration of creatine kinase (CK); perceived muscle soreness (delayed-onset muscle soreness, DOMS) and perceived recovery (physical performance capability, PPC); and stress (MS) were measured before and after the STM and after 3 days of recovery. After completing the STM, there were significant ($p \leq 0.05$) performance decreases in 1RMest (%[INCREMENT] ± 90% confidence limits, ES = effect size; -7.5 ± 3.5, ES = -0.21), MVIC (-8.2 ± 4.9, ES = -0.24), CMJ (-6.4 ± 2.1, ES = -0.34), MRJ (-10.5 ± 3.3, ES = -0.66), and RSI (-11.2 ± 3.8, ES = -0.73), as well as significantly reduced muscle contractile properties (Dm, -14.5 ± 5.3, ES = -0.60; V90, -15.5 ± 4.9, ES = -0.62). After days of recovery, a significant return to baseline values could be observed in 1RMest (4.3 ± 2.8, ES = 0.12), CMJ (5.2 ± 2.2, ES = 0.28), and MRJ (4.9 ± 3.8, ES = 0.32), whereas RSI (-7.9 ± 4.5, ES = -0.50), Dm (-14.7 ± 4.8, ES = -0.61), and V90 (-15.3 ± 4.7, ES = -0.66) remained significantly reduced. The STM also induced significant changes of large practical relevance in CK, DOMS, PPC, and MS before to after training and after the recovery period. The markers Td and Tc remained unaffected throughout the STM. Moreover, the accuracy of selected markers for assessment of fatigue and recovery in relation to 1RMest derived from a contingency table was inadequate. Correlational analyses also revealed no significant relationships between changes in 1RMest and all analyzed markers. In conclusion, mean changes of performance markers and CK, DOMS, PPC, and MS may be attributed to STM-induced fatigue and subsequent recovery. However, given the insufficient accuracy of markers for differentiation between fatigue and recovery, their potential applicability needs to be confirmed at the individual level.

Raeder, C., Wiewelhove, T., Schneider, C., Döweling, A., Kellmann, M., Meyer, T., Pfeiffer, M. & Ferrauti, A. (2017). Effects of active recovery on muscle function following high-intensity training sessions in elite Olympic weightlifters. Advances in Skeletal Muscle Function Assessment, 1 (1), 1-10

This study investigated whether the repeated use of an active recovery (ACT) program is beneficial for promoting recovery of muscle function during an intensive training phase in elite Olympic weightlifters. Using a crossover design, eight competitive weightlifters (7 male; 1 female) from the German national Olympic team participated in a two-day microcycle, comprising of four high-intensity training sessions, with either ACT or passive recovery (PAS) following the session. Barbell velocity during the clean pull, countermovement jump (CMJ) height, muscle contractile properties using ten-siomyography (TMG), creatine kinase activity (CK), muscle soreness (DOMS) and perceived overall recovery and stress were measured. After termination of the microcycle, the sport-specific performance during all clean pull intensities (85% 1RM, ACT: Effect size (ES) = -0.20, PAS: ES = -0.50; 90% 1RM, ACT: ES = -0.29, PAS: ES = -0.35; 95% 1RM, ACT: ES = -0.41, PAS: ES = -020; P > 0.05) decreased. Both CK (ACT: ES = 2.11, PAS: ES = 1.41; P = 0.001) and DOMS (ACT: ES = 1.65, PAS: ES = 2.33; P = 0.052) considerably increased. Similarly, ratings of perceived recovery and stress were adversely affected in ACT and PAS, whereas changes in CMJ height and TMG muscle contractile properties remained trivial in both conditions. No practically meaningful differences in changes of the outcome measures were found between ACT and PAS, although there were variable individual responses to ACT. In conclusion, the short-term implementation of an individualized ACT program does not seem to enhance recovery from training-induced fatigue more effectively than PAS. However, because of the inter-individual variability in responses to ACT, it may be beneficial at the individual level.

Raeder, C., Wiewelhove, T., Westphal-Martinez, M.P., Fernandez-Fernandez, J., De Paula Simola, R.A., Kellmann, M., Meyer, T., Pfeiffer, M., & Ferrauti. A. (2015). Neuromuscular fatigue and physiological responses after five dynamic squat exercise protocols. Journal of Strength and Conditioning Research, 30 (4), 953-965

This aimed to analyze neuromuscular, physiological and perceptual responses to a single bout of 5 different dynamic squat exerciseprotocols. In a randomized and counterbalanced order, 15 male resistance-trained athletes (mean ± SD; age: 23.1 ± 1.9 years, body mass: 77.4 ± 8.0 kg) completed traditional multiple sets (MS: 4 × 6, 85% 1 repetition maximum [RM]), drop sets (DS: 1 × 6, 85% 1RM + 3 drop sets), eccentric overload (EO: 4 × 6, 70% 1RM concentric, 100% 1RM eccentric), flywheel YoYo squat (FW: 4 × 6, all-out), and a plyometric jump protocol (PJ: 4 × 15, all-out). Blood lactate (La), ratings of perceived exertion (RPE), counter movement jump height (CMJ), multiple rebound jump (MRJ) performance, maximal voluntary isometric contraction force, serum creatine kinase (CK) and delayed onset muscle soreness were measured. Immediately post exercise, La was significantly ($p < 0.001$) higher in FW (mean ± 95% confidence limit; 12.2 ± 0.9 mmol·L) and lower in PJ (3.0 ± 0.8 mmol·L) compared with MS (7.7 ± 1.5 mmol·L), DS (8.5 ± 0.6 mmol·L), and EO (8.2 ± 1.6 mmol·L), accompanied by similar RPE responses. Neuromuscular performance (CMJ, MRJ) significantly remained decreased ($p < 0.001$) from 0.5 to 48 hours post exercise in all protocols. There was a significant time × protocol interaction ($p \leq 0.05$) in MRJ with a significant lower performance in DS, EO, and FW compared with PJ (0.5 hours post exercise), and in EO compared with all other protocols (24 hours post exercise). A significant main time effect with peak values 24 hours post exercise was observed in CK serum concentrations ($p < 0.001$), but there was no time × protocol interaction. In conclusion, (a) metabolic and perceptual demands were higher in FW and EO compared with MS, DS and PJ, (b) neuromuscular fatigue was consistent up to 48 hours post exercise in all protocols, and (c) EO induced the greatest neuromuscular fatigue.

Schimpchen, J., Wagner, M., Ferrauti, A., Kellmann, M., Pfeiffer, M., Meyer, T.: Can cold water immersion enhance recovery in elite Olympic weightlifters? An individualized perspective. J Strength Cond Res: im Druck

We investigated whether cold water immersion following intensive training sessions can enhance recovery in elite Olympic weightlifters, taking into account each athlete's individual response pattern. The entire German male Olympic weightlifting national team participated in the study (n=7), ensuring collection of data from elite athletes only. Using a randomized cross-over design, the athletes went through two high intensity training microcycles consisting of five training sessions that were either followed by a cold water immersion or passive recovery. Barbell speed in a snatch pull movement, blood parameters as well as subjective ratings of general fatigue and recovery were assessed throughout the study. Physical performance at two snatch pull intensities (85% 1RM: -0.15% vs. -0.22%, P=0.94; 90% 1RM: -0.7% vs. +1.23%, P=0.25) did not differ significantly (condition x time). While questionnaires revealed a significant decline in ratings of overall recovery (P<0.001) and a significantly higher rating of overall stress (P=0.03) over time, no significant differences between conditions (P=0.14; P=0.98) could be revealed. Similarly, neither of the analyzed blood parameters changed significantly between conditions over time (CK: P=0.53; Urea: P=0.43; Cortisol: P=0.59; Testosterone: P=0.53; Testosterone:Cortisol ratio: P=0.69). In general, CWI did not prove to be an effective tool to enhance recovery in elite Olympic weightlifters over a three day intensive training period. However, even though the group was rather homogeneous with regard to performance, there were considerable inter-subject differences in their response to CWI. It appears that athletes are best advised on a case-by-case basis.

Skorski, S., Hammes, D., Schwindling, S., Veith, S., Pfeiffer, M., Ferrauti, A., Kellmann, M., Meyer, T.: Effects of training induced fatigue on pacing patterns in 40 km cycling time trials. Med Sci Sports Exerc: 47, 2015: 593-600

INTRODUCTION:
In some endurance sports, athletes complete several competitions within a short period, resulting in accumulated fatigue. It is unclear whether fatigued athletes choose the same pacing pattern (PP) as when they have recovered.

PURPOSE:
This study aimed to analyze effects of fatigue on PP of cyclists during a 40-km time trial (TT).

METHODS:
Twenty-three male cyclists (28.8 ± 7.6 yr) completed three 40-km TT on a cycle ergometer. TT were conducted before (TT1) and after (TT2) a 6-d training period. A third TT was carried out after 72 h of recovery (TT3). Training days consisted of two cycling sessions: mornings, 1 h at 95% of lactate threshold or 3 × 5 × 30 s all-out sprint; afternoons, 3 h at 80% individual anaerobic threshold. Four-kilometer split times (min) and RPE were recorded during TT.

RESULTS:
Performance decreased from TT1 to TT2 (65.7 ± 3.5 vs 66.7 ± 3.3 min; $P < 0.05$) and increased from TT2 to TT3 (66.7 ± 3.3 vs 65.5 ± 3.3 min; $P < 0.01$). PP showed a significant difference between TT1 and TT2 ($P < 0.001$) as well as between TT2 and TT3 ($P < 0.01$). PP in TT1 and TT3 showed no significant difference ($P > 0.05$). In TT1 and TT3, cyclists started faster in the first 4 km compared with TT2. RPE course showed no significant difference between TT ($P > 0.05$).

CONCLUSIONS:
Fatigue reversibly changes the PP of cyclists during a 40-km TT. Participants reduced their power output until premature exhaustion seemed very unlikely. This supports the assumption that pacing includes a combination of anticipation and feedback mechanisms.

Wiewelhove, T., Raeder, C., Meyer, T., Kellmann, M., Pfeiffer, M., & Ferrauti, A. (2015). Markers for routine assessment of fatigue and recovery in male and female team sport athletes during high-intensity interval training. PLoS One, 10 (10), 1-17

Our study aimed to investigate changes of different markers for routine assessment of fatigue and recovery in response to high-intensity interval training (HIIT). 22 well-trained male and female team sport athletes (age, 23.0 ± 2.7 years; VO2 max, 57.6 ± 8.6 mL · min · kg(-1)) participated in a six-day running-based HIIT-microcycle with a total of eleven HIIT sessions. Repeated sprint ability (RSA; criterion measure of fatigue and recovery), countermovement jump (CMJ) height, jump efficiency in a multiple rebound jump test (MRJ), 20-m sprint performance, muscle contractile properties, serum concentrations of creatinkinase (CK), c-reactive protein (CRP) and urea as well as perceived muscle soreness (DOMS) were measured pre and post the training program as well as after 72 h of recovery. Following the microcycle significant changes ($p < 0.05$) in RSA as well as in CMJ and MRJ performance could be observed, showing a decline (%Δ ± 90% confidence limits, ES = effect size; RSA: -3.8 ± 1.0, ES = -1.51; CMJ: 8.4 ± 2.9, ES = -1.35; MRJ: 17.4 ± 4.5, ES = -1.60) and a return to baseline level (RSA: 2.8 ± 2.6, ES = 0.53; CMJ: 4.1 ± 2.9, ES = 0.68; MRJ: 6.5 ± 4.5, ES = 0.63) after 72 h of recovery. Athletes also demonstrated significant changes ($p < 0.05$) in muscle contractile properties, CK, and DOMS following the training program and after the recovery period. In contrast, CRP and urea remained unchanged throughout the study. Further analysis revealed that the accuracy of markers for assessment of fatigue and recovery in comparison to RSA derived from a contingency table was insufficient. Multiple regression analysis also showed no correlations between changes in RSA and any of the markers. Mean changes in measures of neuromuscular function, CK and DOMS are related to HIIT induced fatigue and subsequent recovery. However, low accuracy of a single or combined use of these markers requires the verification of their applicability on an individual basis.

Wiewelhove, T., Raeder, C., Meyer, T., Kellmann, M., Pfeiffer, M., & Ferrauti, A. (2016). Effect of repeated active recovery during a high-intensity shock microcycle on markers of fatigue. International Journal of Sports Physiology and Performance, 11 (8), 1060-1066

To investigate the effect of repeated use of active recovery during a 4-d shock microcycle with 7 high-intensity interval-training (HIT) sessions on markers of fatigue. Eight elite male junior tennis players (age 15.1 ± 1.4 y) with an international ranking between 59 and 907 (International Tennis Federation) participated in this study. After each training session, they completed 15 min of either moderate jogging (activerecovery [ACT]) or passive recovery (PAS) with a crossover design, which was interrupted by a 4-mo washout period. Countermovement-jump (CMJ) height, serum concentration of creatine kinase (CK), delayed-onset muscle soreness (DOMS), and perceived recovery and stress (Short Recovery and Stress Scale) were measured 24 h before and 24 h after the training program. The HIT shock microcycle induced a large decrease in CMJ performance (ACT: effect size [ES] = -1.39, $P < .05$; PAS: ES = -1.42, $P < .05$) and perceived recovery (ACT: ES = -1.79, $P < .05$; PAS: ES = -2.39, $P < .05$), as well as a moderate to large increase in CK levels (ACT: ES = 0.76, $P > .05$; PAS: ES = 0.81, $P > .05$), DOMS (ACT: ES = 2.02, $P < .05$; PAS: ES = 2.17, $P < .05$), and perceived stress (ACT: ES = 1.98, $P < .05$; PAS: ES = 3.06, $P < .05$), compared with the values before the intervention. However, no significant recovery intervention × time interactions or meaningful differences in changes were noted in any of the markers between ACT and PAS. Repeated use of individualized ACT, consisting of 15 min of moderate jogging, after finishing each training session during an HIT shock microcycle did not affect exercise-induced fatigue.

Wiewelhove, T., Fernandez-Fernandez, J., Raeder, C., Kappenstein, J., Meyer, T., Kellmann, M., Pfeiffer, M., & Ferrauti, A. (2016). Acute responses and muscle damage in different high-intensity interval running protocols. The Journal of Sports Medicine and Physical Fitness, 56 (5), 606-615

Our study aimed to evaluate the acute responses and exercise-induced muscle damage of five different high-intensityinterval training (HIIT) protocols adjusted by the maximum velocity obtained in the 30-15 Intermittent Fitness Test (VIFT). Sixteen well-trained intermittent sport players (mean ± SD; age, 24.6±2.7 years; VO2max, 58.3±5.9 mL/kg/min) participated in five different HIIT protocols separated by six days in between (P240: 4×4 min at 80% VIFT; P120: 7×2 min at 85%; P30: 2×10×30 s at 90%; P15: 3×9×15 s at 95%; P5: 4×6×5 s sprints). Blood lactate (La), blood pH, serum creatine kinase (CK), heart rate (HR), session rating of perceived exertion (session-RPE), delayed onset muscle soreness (DOMS) and countermovement jump (CMJ) height were measured. A significant main effect for protocol ($P<0.05$) was found for the acute responses of HR, session-RPE and La with values increasing in longer intervals from P15 to P120 and P240 while blood pH responded inversely. In contrast, P5 produced the highest La concentration and blood pH decreases. Twenty-four-hour post-exercise CK, DOMS and the decrease in CMJ height were significantly higher after P5 compared to all other protocols ($P<0.05$). HIIT protocols of different interval duration and intensity result in varying acute physiological and perceptual demands and exercise-induced muscle damage. Longer intervals with submaximal intensity lead to higher acute cardio circulatory responses, whereas sprint protocols induce the high-est muscle damage and muscle soreness.